Microscale Transport Processes

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Lecture No # 22

Electro Osmosis (Contd.)

I welcome you to this lecture of Microscale Transport Process, what we have been discussing in the last class were electric double layer.

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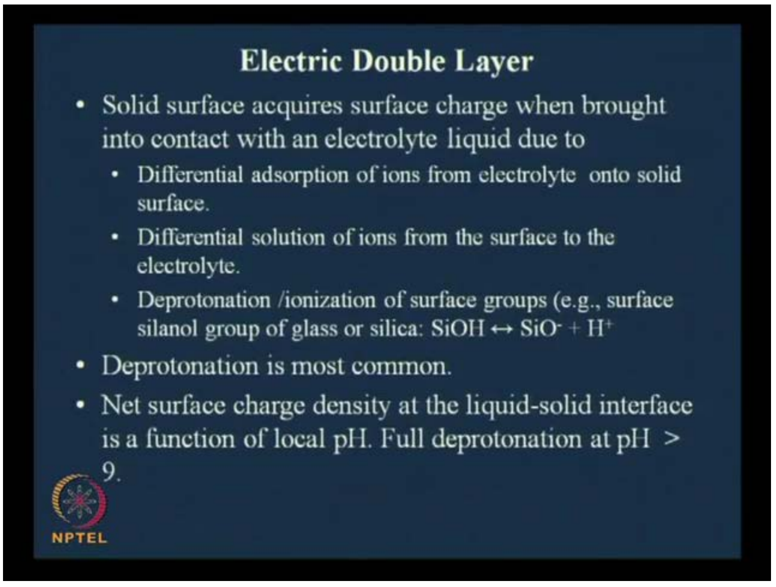

Let me give you a quickbriefing on what we have already discussed, since there was a gap in between. This solid surface acquires surface charge, when brought into contact with an electrolyte liquid due to several reasons. Those reasons are given there,deprotonationor ionization of surface groups that is very common.

So, just because a solid surface and there is an electrolyte in the proximity, there would be some surface charge developing. And net surface charge density at the liquid solidinterface is a function of local pH, because you know what pH is, it is basically hydrogen, ion concentration log of that. So, it is it is it is it is very much related to the pH of the system, full deprotonation at pH greater than 9.

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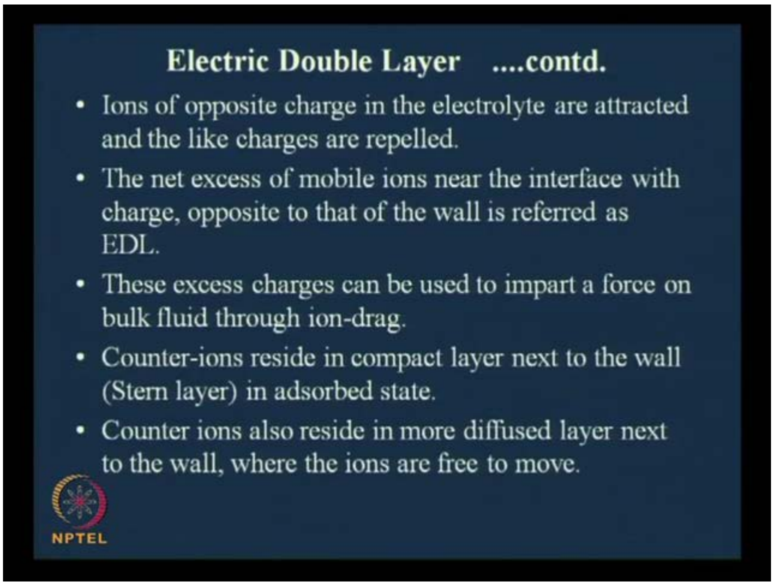

Now, this once there is a surface charge acquiring, oneonce these charges are acquiring on the surface or acquired on the surface, then there would be opposite charges getting attracted. And this is forming an excess of mobile ions near the interface with charge, opposite to that of the wall, and this is referred as electric double layer; these excess charges can be used to impart a force on bulk fluid through ion-drag.

So, the counter-ions reside in compact layer next to the wall which is referred as stern layer, which is in adsorbed state. The other one is a counter-ions that reside in a more diffused layer next to the wall, where the ions are free to move.

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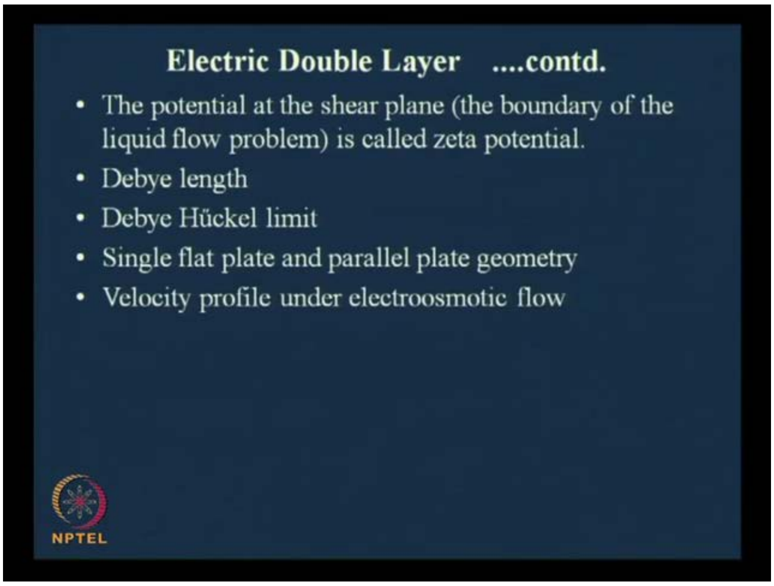

So, what wediscussed in thelast class, we started discussing in the last class is that potential at the shear plane, the boundary of the liquid flow problem is calledzeta potential, and there is something called Debye length, andthis this we discussed in the in the in the last class. Let me let me point out quickly, whatwe hadwe had we had derived few things in the last class.

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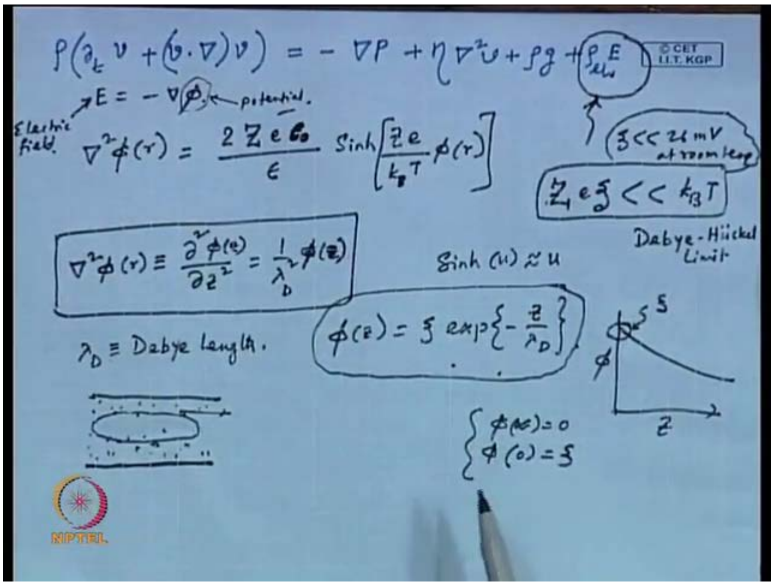

Let me justpoint out thebasic findings there, the basic equations there, first of all we are working with within the framework of Navier-Stokes equation, which appears like this(No audio 02:44 to 03:14). What we mentioned in thementioned previously is that these terms we are all familiar with, del t v is that derivative with respect to time, and v dot delta v you know, but what what we are talking about here, this is the pressure gradient term eta is the viscosity, so and rho g is thecomponent due to gravity. So, this this part you already you are familiar with and this rho e L E we introduced recently, this is the body force term arising from this ion drag, that we talked about. So, we we have this additional body force term present.

Now, what we said in the last class is that, these deltathis this rho e L E this needs to be this needs to be we need to understand this term well, and weneed to see how this term is getting affected, because of this electric double layer. Now, what we have derived in the last class is, something like this thatdel squarepi r that is equal to 2 z e epsilon e c naught z e c naught divided by epsa, this is c naught sin hyperbolic z e by k b T pi of r, this is an expression that we had obtained in the last class.

Now, here we said that for the limit for the limit z e zeta much less than k b T when when this is happening, this is this is this is referred as Debye Huckel limit,when this is when this is happening when when this is when this is happening in that case, this sin hyperbolic can be, you can you can make an approximation here, that sin hyperbolic u is equal to u, when u is small. So, that is exactly what you are doing here.

So, one with this, what we have found in the last class is, this this is this is coming from Taylor series expansion, and ignoring the other higher order terms,what you end what we ended up with in the last class is, del square pi which is for one-dimensional case, this would be equal to del square piz del z square that is equal to1 by lambda D square pi z all right 1 by lambda D square pi zall right. Now, this is an expression that we had, and this expression we said that, here this lambda D is referred as Debye length.

And what is this pi now, pi was basically electric field, this this pi isnothing but, E is equal to minus delta pi, where this E is, this E that is appearing in the Navier-Stokes equation (Refer Slide Time: 07:07). So, E is equal to minus delta pi, what is E, E is the electric field E is the electric field, and this pi is the potential this pi is the potential. So, that is that is how this pi and E they are related, and with the pi we have this expression where lambda D is equal to the Debye length.

This is the case, so this is very straightforward and once you solve this equation solution of this equation would be pretty straightforward, it is referred as, I can I can write this as pi z is equal to zeta exponential of minus z by lambda D. What you can say is, I mean this this limit that we put here, basically this z e pi has to be much less than k b T now, but phi at what point that would be the question people will ask, I mean what pi a,t whatwhat z we are referring to.

So, instead of putting pi at any arbitrary value we put it as zeta,zeta is the value of pi at z is equal to 0 that means, if you plot pi versus z, then it should be dropping and the value here, at z equal to 0, that is referred as zeta, commonly referred as zeta potential, pi is the potential. And for with distance from the wall this pi is decreasing, so at the bulkelectric double layer does not have any any effect, any existence, so pi is decreasing.

So, now, this decrease is thisthe way this is decreasing, this is given by this functionpi z is equal to zeta exponential of minus z by lambda D, where z is the distance from the wall, pi is the potential which is decreasingand at the wall that means, at z equal to 0, pi is equal to zeta this is the expression that this gives (Refer Slide Time: 08:47). So, this is the expression we have, so this expression came assuming this Debye Huckel limit, that is assuming z e zeta much less than k b T.

Now, this is probably a veryhypothetical kind of limit instead of that people are more familiar with limit zeta much less than 26mille volt at room temperature,that is what that is what people aregenerallyfamiliar with this sort of limit. Instead of puttingputting things in symbols, you can put put things in numbers.

So, this is this is what you have, this is the expression that you have, what type ofsituation this is simulating this is simulating a wall which has acquired some charges, and the counter-ions it pulled, and this this expression gives youthe potential as a function of distance from the wall (Refer Slide Time: 09:44). Now, so so you what you are assuming is that at z equal to infinity pi is 0, probably that is that is what was one of the boundary condition you have used, you have used pi infinity is equal to 0, and pi 0 is equal to zeta, so these are the boundary conditions you have used.

Now, the problem in hand that we have is a channel, we are talking about a microchannel, we are not talking about the simple wall. So, if you have a microchannel this we were discussing at the end of the last class; that if you have a microchannel that means, if you have a if you have two walls. One wall here with counter ions accumulating, another wall here with counter ions accumulating and both are pulling the bulk of the fluid.

Now, this part you could refer as bulk, this part you refer as a bulk of the fluid and this bulk of the fluidis dragged by this body force, so if the if that is the case, then you can use the same expression, only your boundary condition will change right (Refer Slide Time: 10:56). That that is that is something which I remember, I was discussing at the end of the last class, that the boundary condition will change. So, what would be the new boundary condition in this case.

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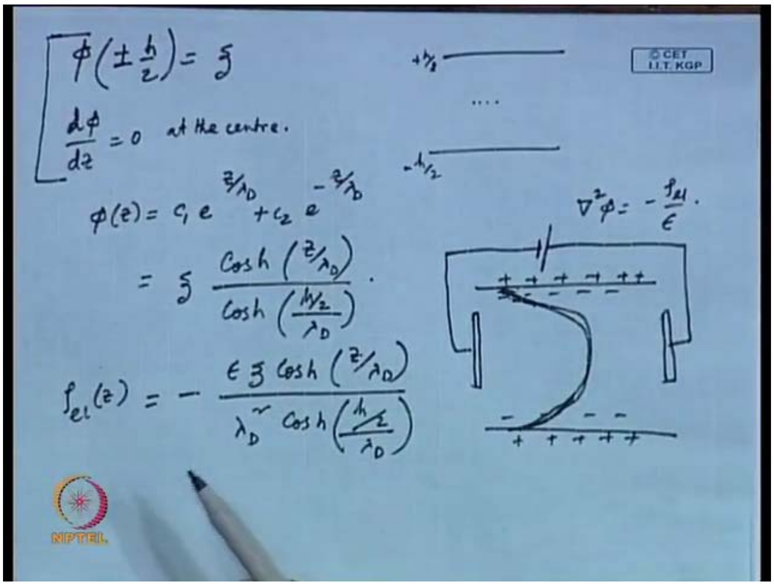

The new boundary condition would be that, pi is equal to pi plus minus h by 2 that is equal to zeta, plus minus h by 2 that means, you are your yourcenter herehere your center was at the wallI mean in the earlier case, but in this case the center is if if this is the channel then the centralize here. So, at plus h by 2 and at minus h by 2, you havethis value of potential is zeta and the other thing is that at the center, there is symmetry existing, so d pi d z is equal to 0 at the center by symmetry.

So, this is the new boundary condition you have, but the governing equation remains same, I mean we do not have any reason to believe that a governing equation should change. So, with these two boundary conditions, you remember in the last case also we came up with this expression; pi z is equal to c 1 e to the power z by lambda D plus c 2 e to the power minus z by lambda D. So, in that in the earlier case we said that, since at z equal to infinity pi is pi has to be finite, rather pi has to be equal to 0. So, this c 1 has to be equal to 0, that was that was our ourrationalto put c 1 as 0.

But, here the situation is different, it is pi plus minus h by 2 is equal to zeta, so that means, you have c 1 as well as c o c 2 both nonzero. So, you have to work it out and what you would get in that case is equal to zeta cos hyperbolic z by lambda D divided by cos hyperbolic h by 2 divided by lambda D right.

So, in that casewhat you would have is rho e l z, what is rho e l z you remember, we have already obtained this expression, you need to go back and see how you have written it, del square pi is equal to minus rho e l z, rho e l by epsa. So, this was an expression we had worked with earlier. So, accordingly this rho e lz would be equal tominus epsa zeta cos hyperbolic z by lambda D divided by lambda D square cos hyperbolic h by 2 divided by lambda Dall right. So, this is the expression you have for rho e l z.

Now,if you come up with a scheme if you come up with a scheme, which is something like this, you have a channel, you have electrode here, this is the electrode and this is another electrode, they are connected (No audio from 15:17 to 15:41) (Refer Slide Time15:15) this is the way it is. Now, if we are interested here in a velocity profile, if we would like to know what would be the velocity profile, because of thispresence of this electrode, because electrodes are required to create a velocitycreate a potential gradient.

And because of this potential gradient we expect that a flow will we expect because of this potential gradient, we will have thethis term appearingrho e l into E this becomes instrumental (Refer Slide Time: 16:21). And so there would be a velocity, even if there is no pressure gradient, suppose this delta p is not thereif delta p is not there we know that there will not be any any flow, but if by some way we can put this we can put a delta pi here, by some means we can put a delta pi here, some means we can make this term non zero, then we can induce a velocity.

We are interested to know what would that velocity is in the micro channel,in in the channelin the channel where we have two walls, if this is the schemewe would like to know what would be these velocity profile. So, for that we need to solve the Navier-Stokes equation with this understanding, with this being pi, with this being rho and we have appropriate E with this we need to solve the Navier-Stokes equation. So, that is exactly what I would be taking up next (Refer Slide Time: 17:06).

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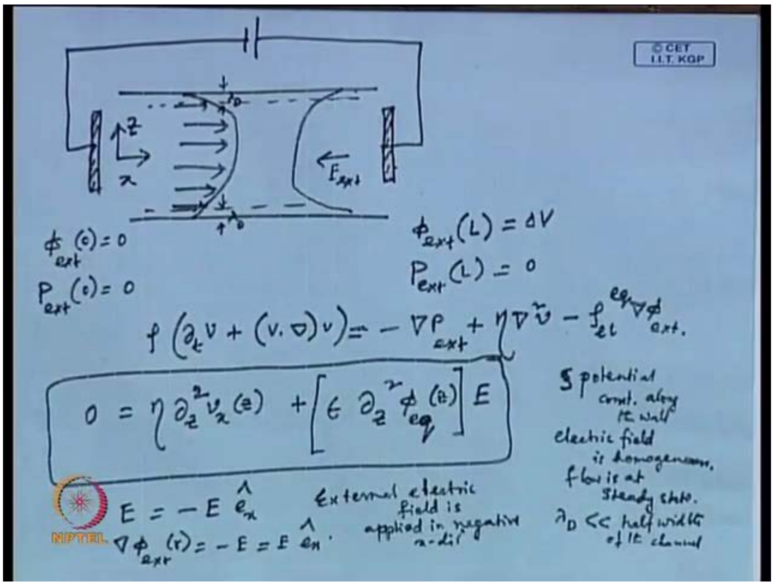

So, let us let us draw this once again, this is an electrode, this is another electrode, this direction is x,this direction is z all right, this direction is z andyou havepi external at z x is equal to 0 is 0, P external at x equal to 0 is equal to 0. Here, the pi external at x equal to L all right at x equal to L that is equal to delta v and p external at x equal to L is equal to 0. So, that means, there is no pressure drop,we are we are expecting the just because, we have put this potential gradient we should expect some velocity happening, because of this Navier-Stokes equation, because of that body force term. So, this is what we need to solve here.

Now,if now nownow there thethere would be this, where is this (()) layer in this case, I would I know that there would be a (()) layer, what is that lambda D, this is lambda Dright, here the lambda D lies, here also there is a lambda D, this is the this this lambda D is the Debye length right. We wewe havewe have defined this lambda, we we have defined this Debye length earlier, so here here the charges are all accumulating, I am not drawing the charges again plus or minus, because that that would confuse.

Now, what was the equation we had at that time, we said the equation was rho del t v plus v dot delta v that is equal to minus delta p external plus eta del square v minus rho e l e q delta piexternal. Now, whether it is minus or plus, that depends on what charges you have here, and the direction of this of this field in which direction you are putting the field. So, here it needs to be minus, because of the charges that you have, because what you have in this case is, the E external will be in this direction, if somebody plots the rho e l e q it would be in this direction, and the velocity profile would be in this direction (Refer Slide Time: 20:41). So, the velocity would be in this direction, the bulk flow will be in this direction whereas; the potential would be in this directionall right. So, that is how this this this sign of this is defined.

Now, if you if you do if you solve this for one-dimensional case, it would be something like this, I meanlet me write the equation first and then I see then I find out what all assumptions we have taken here(No audio 21:16 to 21:54) (Refer Slide Time: 21:16). This is the equation that we have for one-dimension with the assumptions,what all the assumption what are all the assumptions, zeta potential is constant along the wallalong the wall, electric field is homogeneous, flow is at steady state and Debye length is much smaller than the half width of the channel.

So, what you what you what you write here is, E here is equal to minus E e x hat, because E is in negative direction, this this electric flied isexternal electric fieldis applied in negative x direction, delta pi external is equal to minus E that is equal to E e x hat, that we already know. And other thing is that, the velocity term, v velocity is equal to vx which changes with z e x hat.

So, v at any position is, it is v x which changes with z e x(()) that means, velocity is only in the x direction, there is no other component, and delta p external is equal to 0, that you already assumed. So, with these with these with these assumptions and with these understanding, you ended up with this expression Navier-Stokes in one-dimension.

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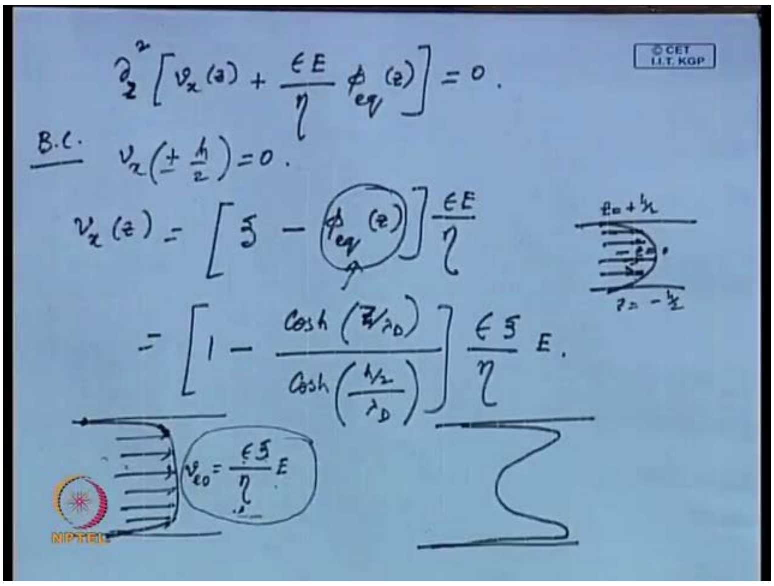

So, once we know that then probably it would be easy to write this expressionin a in a more compact manner as, del z square v x z plus epsa E divided by eta pi e q z, this quantity is equal to 0, that is that is exactly what we what we had in the last slide. (Refer Slide Time: 25:00) if you see this is theexpression we have, so instead of writing it this wayyou take this del z square, and put everythingwithin the within del z squareall right, so it is the derivative.

So, basically del square, this whole thing del z square that is equal to 0, that is what you say and you know the boundary condition here boundary condition here is that v x at plus minus h by 2 that is equal to 0, because we assumed that at the wall, whether it is upper wall or the lower wall, the stern layer is existing. So, it is all adsorbed and there is no velocity,that that is firmly attached to the wall.

So, at the wall v x is equal to 0, this is the boundary condition you have, and this is the governing equation you have, this is the governing equation you have of course, there would be some symmetry at the centerthat that is always thereI mean, if youneed to we can use that that as boundary condition, as well or it will follow automatically (Refer Slide Time: 25:47). Now, this is the governing equation and this is the boundary condition, the solution to this equation would bev x z that is equal to zeta minus pi e q z into epsa E divided by eta, this is the solution to this equation solution to this governing equation with thisboundary condition in place.

Now,now if you if you want to if you want to know what is what is pi z what is pi z,if we if we look at this pi z,if we if we bringing those earlier slides, where we had just introduced this, what was the pi z we had at that timeyou remember,we we werewe were trying to find out what how would the pi z look, how the potential changes right.

We have been trying to find out in the beginning of the class, how the potential changes and we said, if we have simply a wall and extending this this electric double layer simplythe bulk extends to infinity, just only one wall we had this expression with lambda D being the d by length and pi would change with z like this. Then we said, if we have two walls, then we have the bulk in the middle and we have electric double layer present here as well as there, then we said that a governing equation for pi remains same in that case, and the boundary condition will change, this is the boundary condition at plus minus h by 2 this is equal to zeta, and at the center symmetry exist.

So, this is what we said was the case with pithe potential, and then wewe came with this expression for the potential pi is equal to zeta into cos hyperbolic this divided by this. So, this is the case for a channel, this is the case for a single wall right. So, this is this is this is the case for a channel, so we said the pi will follow this expression. So, now we wewewe intentionally we we developed this expression for pi, because we know this pi would be handy here,here what did we do, we put the body force term in in the Navier-Stokes equation and solved it for one-dimension solved it for one-dimension.

And by solving this for one-dimension with this boundary condition that, at the wall the velocity is 0 with this boundary condition, we came up with this expression, now we need to replace this pi, because pi does not this pi will come from hereall right (Refer Slide Time 28:59). So, this pi we we have intentionally we developed this pi for a channel, with two walls to be usedas part of this expression, because our final aim at the very outset I said is to obtain a velocity profile first thing, and second thing is to find out how much how much flow we we havetwo issues here.

When it comes to electroosmotic pumping we have basically two issues, one is that how much velocity how much average velocity you can generate, suppose I put this pump in place, how much velocity it can generate, when there is absolutely no pressure gradient existing. But, still by simply by electroosmotic flow you are generating, so much of velocity that is one issue. Second issue isI mean immediately you will question is where will you get such ideal situation that, there is no pressure dropI mean if you if you are pumping something then, there would be a back pressure, you would be pumping against a back pressure. So, up to whatback pressure it can it can it can deliver the fluid, because if the back pressure isbeyond the limit then there will absolutely be, there will be no flow.

So, if we have a back pressure then, how would be the velocity profile and what would be the flow rate. Now, what we are doing now is we are obtaining the velocity profile, with the assumption that pressure at x equal to 0, and pressure at x equal to l both are both are0, p external at x equal to 0 is 0, p external at x equal to l is equal to 0, and pi external this is 0 here, and this is delta v here all right (Refer Slide Time: 30:31).

So, with this condition we are coming, so this is the first case we are solving, later on what we will do is we instead of putting it 0, we will putput some pressure here, put some back pressure here that means, you are pumping against the back pressure, and then we would like to know what would be the velocityprofile. So, first case no pressure we are all we are almost we are close to getting the velocity profile, this is the velocity profile we obtained and this pi e q has to be replaced by this expression that we have already gotten we have already gotten for a two channel, two wall system.

For a channel system not a single wall system, for awall system this is the expression that we already have. So, if we bring in that expression there, so then the v x z would be equal to 1 minus cos hyperbolic z by lamdaD divided by cos hyperbolic h by 2 divided by lamdaD, h by 2 is the half aperture intoepsa zeta divided by etainto E, this is the expression you have for the velocity profile.

See, I have a z term here, this z term is changing, z is equal to 0 where, if this is the channel I am having an electroosmotic flow taking place through this channel, z is equal to 0 here, z is equal to plus h by 2 here, z is equal to minus h by 2 here. So, within this framework the velocity is velocity I have a velocity profile, and these velocity profile is expression for this velocity profile is given by this expression.

Now, if you ever get a chance to plot this, I mean you can plot this you can you can take some sample values and you can plot v x, just the way we have plotted for a poiseuille flow, we have plotted parabolic velocity profile and all. So, if somebody wants to plot thisexpression, what you will end up with seeing is thatthe velocity profile looks like this, (No audio from 33:12 to 33:24) (Refer Slide Time: 33:12) it is pretty much flat. And there is minor change; I mean it has to be 0 here, so from 0 to the final value,that happens within a short distance that happens within a short distance that is that is a trend of this this expression. So, this is pretty much flat and if somebody wants to know, what is this velocity he will find probably you can check with the limit, as well it will come that way, that this the this this part of the velocity thisv, this is actually referred as e o, v e o electroosmotic velocity, which is epsa zeta divided by eta into e.

So, this is this is this is predominantly this is the velocity over the most part of the channel, and near the wall it the velocity changes from here to 0. So, for all practical purposes, not for all practical purposesI mean you can you can you canif somebody wants to know,what is the what is electroosmotic velocity, for quick calculation you can use this expression,this is this is pretty much the electroosmotic velocitywhich is which is constant for most of the cross section.

Look at the look at the look at the parameters that is involved here epsa zeta,zeta is that zeta potential of that electrolytewalls that system, the you have a solution, you haveions moving around and you have developed some zeta potential on the wall, it is that zeta. Eta is the viscosity of the fluid, which is just simply coming because, you have that Navier-Stokes equation and there you have eta del square v term, so this eta is coming from there.

E is the electric field that we imposed, so this is the electroosmotic velocity that you have. So, if somebody wants to find out, what would be electroosmotic velocity under certain situation, so he has he needs to use this formula, and if he needs to know really how the profile would be, and if he is asked to draw precisely, what the profile would be then he needs to resort to this expression all right. So, this is this is what you have as far as theas far as thisthis this electroosmotic velocity is concerned.

Now, the issue here is that, we we have assumed we have assumed here that this as I said pi external is equal to 0, P external is equal to 0, now what we will do is, this is delta v this is fine, here instead of 0 we would put this as delta p that means, we will try to find if it is if it has to act as a pump it has to act against a back pressure, that is the idea right. You have to pump the fluid through a channel; you have to pump the fluid through certain media like this, so that media or that channel will impose a back pressure, if the outlet of the channel let us say open to atmosphere. But, to to get the flow going through that media, you you need overcomes on back pressure, so instead of 0 we need to put this as delta P. So, so in that case this delP term in Navier-Stokes equation, we we had this we had this del P term earlier,this del P term was not used at all this del P term was not used at all in the Navier-Stokes equation (Refer Slide Time: 37:00).

Now, what we will do is, we will use this del P termin a sense that, this this this del P termwould bethis minus delta p external, now we will have minus delta P external that is equal to, then then it will have a value, it will be minus delta p by L e x hat. So, this this would be this is something which we would be imposing, so if we impose this, what would be the velocity profile,that is what that is what people would be looking at.

Now,before I before I give you the before I give you before I get into the expression part of it, because this again we will have several symbols, before we get into this on the side of this plot, I would like todraw how the how the velocity profile would be, I mean can you think about it, how howhow would the velocity profile be in such case, that here that there is no back pressure, but in this case there will be a back pressure. You will be surprised to see that the velocity profile in this case would be like this (No audio from: 38:21 to 38:33) (Refer Slide Time 38:21). Basically, this part you are following the electroosmotic flow, because this here you have charges and this charge is trying to drag the fluid.

Because, of this ion drag there is the bulk fluid is also drag with the ion and all this things are happening, so it would be just like this velocity near the wall however, you have a back pressure and this is acting like simple parabolicvelocity profile, in the opposite direction, because you have a P there, and you have the you do not have theP on this side. So, you haveyou have this kind of trend, so this would be the velocity profile that we are looking at.

And with this velocity profile, now you need to know how much delta P, against how much delta P this electroosmotic pump can still work all right, because you have a pump in place and you need to knowyou are you are pumping it through a media and that media would give a back pressure of so many pascals, so many atmospheres, so many second (()). So, you need to know whether the pump can deliver that kind of pressure or not otherwise, this pump will not work.

So, we need to solve this velocity profile, and we need to find out when this velocity is what the limiting value is, when this velocity is 0 that is the limit. So, thewhen when does that limit reach, when when is that limit reached and what is the corresponding back pressure. So, you know that, that is back pressure that the pump cans, that pump can (()) pump against that back pressure, beyond that pump will fail. So, for that we need toknow the velocity.

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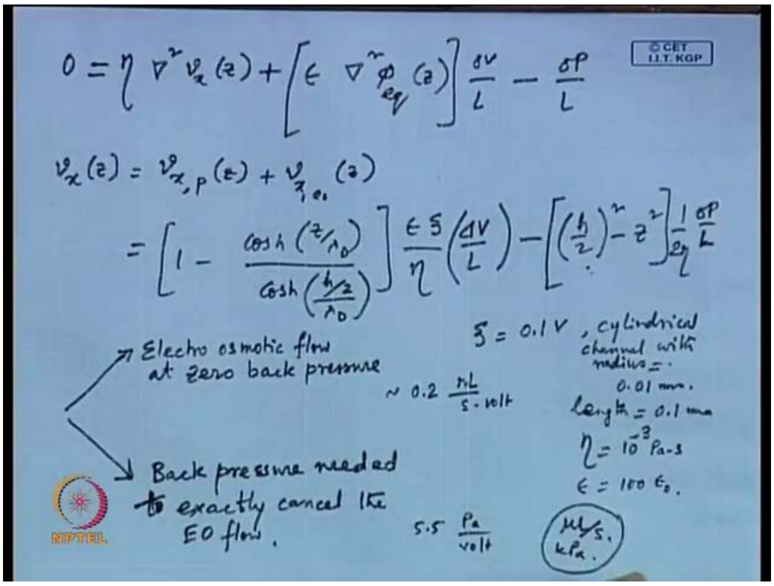


So, with this understanding let me let me let me point out that, thisthis this expression would behere we would be looking at, the Navier-Stokes equation would be something like this. The Navier-Stokes equation would be eta del square v x z plus epsa del square pi e q z delta v by L minus delta p by L, this is the expression that you have all rightthis is the expression that you have. And typically the solution here, I mean this this this this system of equation that allows you to may get a solution, which is basically superimposed, called superimposed velocity, the velocity that is arising frompressure and the velocity that is arising from electroosmotic flow.

So, the sum of these two, so it would be like this 1 minus cos hyperbolic z by lamdaD divided by cos hyperbolic h by 2 divided by lamdaD into epsa zeta divided by eta, I am not writing it as E instead of this I am writing it as delta v by L, because that is easier to understandminus, this part is the pressure component h by 2 whole square minus z square 1 by 2 eta delta p by L delta p by L all right. So, this is the component which is arising from pressure, and this is the component which is arising from electroosmotic velocity, and this is the combined v x z, and if this v x z is plotted you will get the profile which we have shown here (Refer Slide Time: 42:36). In this caseyou will get this kind of profile.

Now, we are not very muchI mean I mean profile is fine, we we intuitively also we new that there is a profile, what we are interested in at this point here is two things, that I mentioned in in in the beginning itself, two issues or two concerns are here. One is electroosmoticflow at 0 back pressures, and the other point is back pressure neededto exactlycancel theE o flow.

There are two issues here, I meanyou you must appreciate this, one is that 0 back pressure what is the electroosmoticvelocity you have, electroosmotic flow you have and the other is up to what back pressure it can still have an electroosmotic flow, beyond which the flow will stop. So, from the design point of view, if somebody is going to use this pump thesethese two factors are immensely important to him. Now, if we pick up some standard values for example, if zeta is equal to 0.1 volt, for a cylindrical channelwith radius is equal to say 0.01 millemeter.

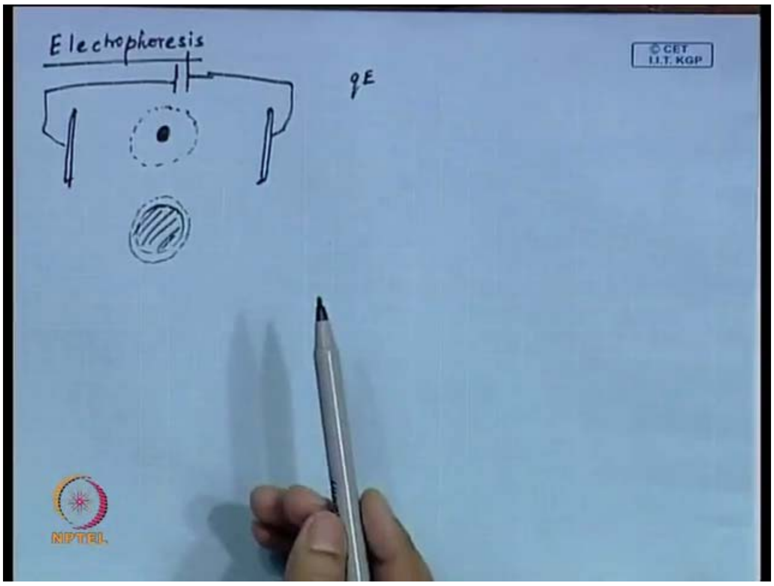
For length is equal to 0.1 millemeter,eta is equal to 10 to the powereta is equal to 10 to the power minus 3, what iswhat is the viscosity of water minus 3 Pascal's second, Pascal second and if the epsa is equal to say you take some value of say 100epsa naught, you get about this this electro osmotic flow this electroosmotic flow would be about 0.2 nanoliter per second per volt. And this back pressure would be 5.5 Pascalper volt that means, you apply 1 volt of delta v across this electrode, you getthis much of flow and you get this much of back pressure, beyond this back pressure the flow will stop.

So, naturally these schemes does not, see this does not seem to be very attractive proposition, because the flow rate is pretty small and the pressure drop pressure also it can stand is very small, you must appreciate. So, there is the way out and people who are using this electroosmotic pump, they are notusing a single channel, they have overcome this problem, and they have they have used this pump successfully, with the flow rate that we expect typically in a in a microchannel system.

What they do is, they use several channels not just single channel and by several channelI mean you can you canhave a porous medium that means, you can have beads, several beads packed inside the youyouyou have a larger channel and within the channel you have several beads. So, that you have multiple parallel channels operating simultaneously, and that can overcome this problem all right, because this would be this would be evident if you if you if you look at thisthis problem itself. I mean ifif you look at the expression (No audio from 47:30 to 47:54), if you if you have large number oflarge number of channels then this this this problem can becan be circumvented, this this problem you can you can get away with this problem.

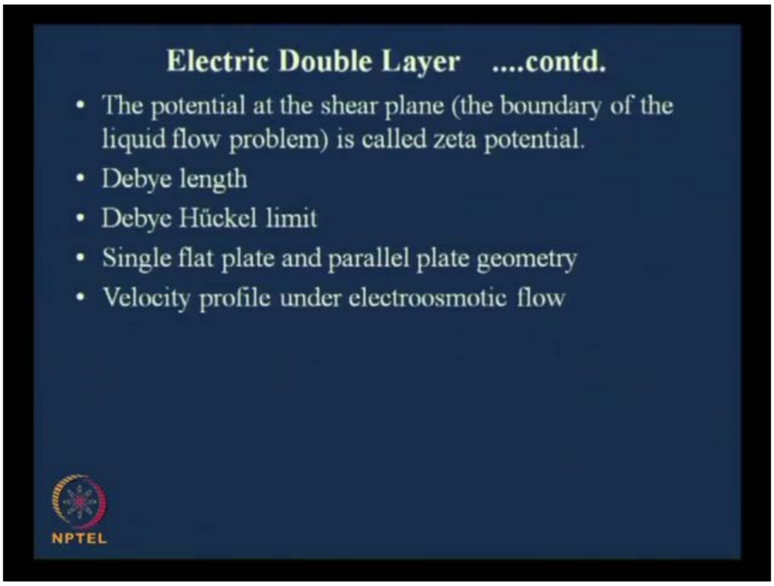
And in fact, you can have the pressure dropto the to the tune of say, then then you you can have the flow rate to the tune of microliter per second pressure drop several kilopascals. So, these are these are these are very much possible with with a channel, with either with (()) or closely packed glass spheres. So, that you can you can generate large number of parallel channelsthat isthat that is there. So, any electroosmotic pump would become comprised of such (()) inside the channel orthe channel will be packed with beads, so that you can several parallel channels operating (No audio from 48:58 to 49:15).

(Refer Slide Time: 49:27)



I will see if we if we if we have any, if we need any clarification on this issue,we can we can probablydiscuss this in the next class. Otherwise, the next topic that I will pick up is electrophoresis; next topic that I will be picking up is electrophoresis.

(Refer Slide Time: 49:41)

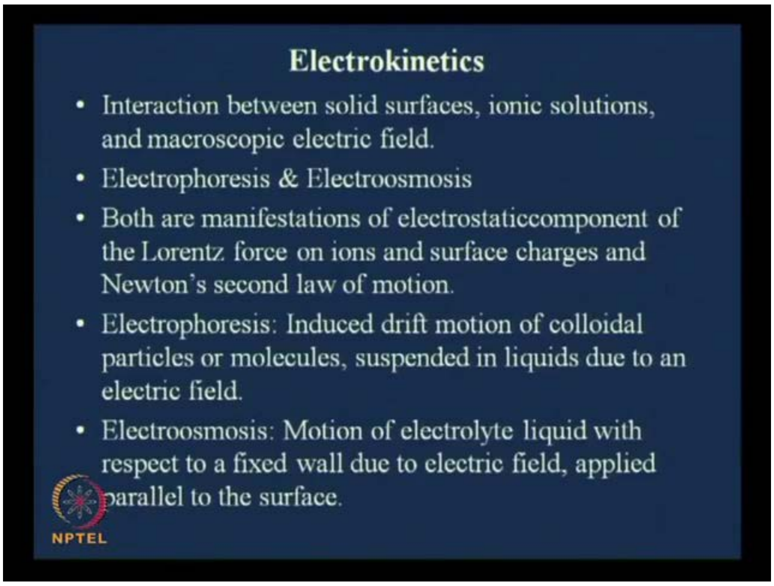


So, if Iif I quickly quickly look at, what we had in this in this power point slide is that, we have discussed about the potential at the shear plane, the boundary of the liquid flow problem and which is called zeta potential D by length we discussed which is lambda D, basically Debye Huckel limit, we discussed. This all our analysis is based on, the entire analysis is based on Debye Huckel limit that means, this sin hyperbolic u is equal to u,that that we wewe had that Taylor series expansion, we note the higher order terms with that understanding. So, that is the Debye Huckel limit.

Single flat plate and parallel plate geometry,that we I think we understood by now, that in one case we have simplythatone plate, and we have the pi changing with z and in other case you have two platesat z equal to plus h by 2 and z equal to minus h by 2, that we have looked into and the velocity profile under electroosmotic flow, that we have already established.

The next topic that I that Ithat I am going to pick upis basically electrophoresis, electrophoresiselectrophoresis once againI mean this isthis is induced drift motion ofcolloidal particles we, I had a definitionof electrophoresis at the very beginning.

(Refer Slide Time: 51:07)



You remember,electrophoresis is induced drift motion of colloidal particles or molecules suspended in liquids due to an electric field. So, what we have is, we have an electrode here, we have another electrode here, and we have a particlewe have a particle here (Refer Slide Time: 51:21). Now, this particlehas certain charge in this and you have already imposed an electric field, you have imposed an electric field E and this particle has charge q.

So, if the particle is small, then the force that is exerted here, that would be equal to q into E and that force, you will be that force would be imposed on the particle,if if theseif these are connected if these are connectedif these are connected this that force would imposed on the particle. On the other hand, if this particle has to move, because of this force there would be drag imposed (()), if it is in the liquid if this is the particle moving, so then there will be a drag force. So, there will be a balance between these two forces.

So, we we would be we would be discussing in the next class,what would be the what would be the velocity of this particle, if the particle is smallsmall in the sense, the particle is small and it has a huge Debye length, becausethis particle there would be a formation of Debye length formation of an electric double layer around it or the particle is big this is the particle and you have a small double layerforming around it (Refer Slide Time: 52:45). And then this would be pooled, so what would be the velocity this particle will acquire, so if youidea of this electrophoresis at the very outset, we wementioned is that if if you have particles several such particles of different size or charge, and this particle would be attracted to the electrode by different forces. So, if you hold this, under this electric field for some time you will see that particles of same size and charge, they would be accumulating in one band particles which could not flow at that velocity,they will not be they will be at some other place.

So, you will be having some kind of classification within this within this within thiswithin the body of this material. So, that classification we are we are looking at that, that is that is what we would be calling electrophoresis, now what we would be doing is we will be taking these two casesseparately in the next class.

And we will see howhow we defined force and how we defined the velocity in this case, and what would be the utility of this whole scheme; this is very good to find out, what what particles you have, this particle could be a cell, biological cell, this particle could be a clay particle. (())particles have different sizes and charges that can beclassified using this using this technique. I have that is all I have for today's class, if and and I will try to see if there is any any outstanding question on this electroosmotic flow, I will try toaddress them in tomorrow's class, that is all I have for today, thank you.