Microscale Transport Processes

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Module No. # 01

Lecture No. # 27

Slip Flow

Start welcome to this lecture on Microscale Transport Process, what we were discussing in the last class is Slip Flow.

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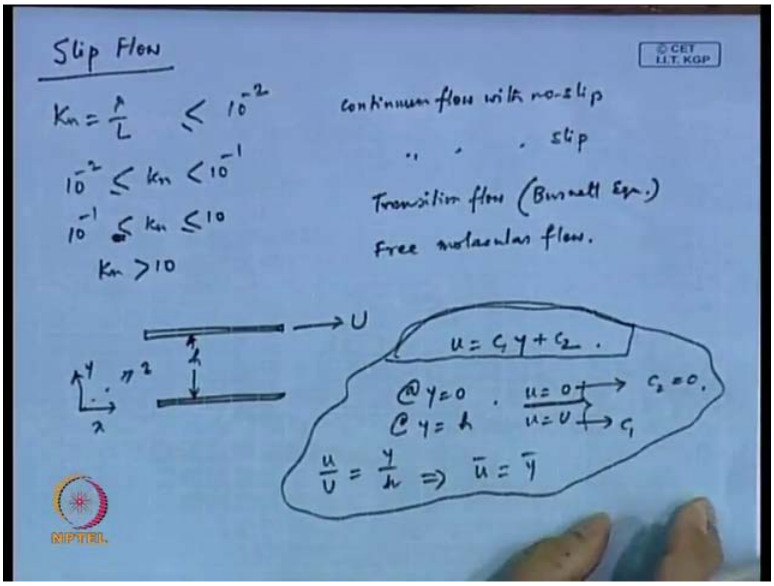

We we startedwe started working onwhat we call slipslip flow, what what we what we said at the very outset that depending on what is the value of Knudsen number, Knudsen number is lambda by L depending on what is the value of Knudsen number, you can be in different regimes. If Knudsen number is less than 10 to the power minus 2, then it would be continuum flow with no slip flow with no slip; and if it is between 10 to the power minus 2 and 10 to the power minus 1, then it would be continuum flow with slip.

And then if it isbetween 10 to the power minus 1 and 10, then it isthis is considered as transition flowbetweencontinuum and free molecular flow, and the equation that is used is Burnett equation and Knudsen number greater than 10, this is referred as free molecular flow where molecular dynamics collision between molecules, that will govern theproperties, continuum assumption cannot be taken.

Now, what we are doing in the last class is we were trying to solve something which is referred as micro cuvette flow that means, there is one plate which is moving at constant velocity U and there is another plate which is fixed, this plate is moving at a velocity U. And in the last class, what we did is from Navier-Stokes equation, we showed that the solution would besomething like this u is equal to c 1 y plus c 2, that we have already derived in the last class.

That this is this is a this is a standard form, because of certain assumptions we had taken several assumptions, we had taken translation invariance of the set upalong,alongif this is x, this is y andperpendicular to the paper is z, then there are translation invarianceof the set up, along x and z direction, only u will vary only in y direction andthere isonly pressure, there is no pressure present. So, only pressure present is hydrostatic pressure that is cancelled out with the gravity and things like that. So, with certain assumptions we ended up with this expression, u is equal to c 1 y plus c 2.

Andwhat we said is that for no slip boundary condition, at y is equal to 0, u is equal to 0 and at y is equal tosome value, what did we call last timeh yes, this isat y is equal to h u is equal to capital U. So, this is this is what we this is what we have and the with this boundary condition we said that from the first boundary condition immediately we have c 2 is equal to 0, and fromthe second boundary condition we get a value of c 1.

So, that is how we ended up with this formula u by capital U is equal to y divided by h, in dimensionless form you can write u bar is equal to y bar alright, so this is this is this is the formulation using Navier-Stokes equation with no slip boundary condition. No slip means u is equal to at the wall the velocity of the wall thefluid assumes, fluid fluid attains the velocity of the wall that isthat is the idea. Now, if you impose a slip boundary condition, firstI meanI mean I mentioned in the last class is this equation remains same, this is the governing equation and this remains same.

However, the boundary conditions will not be same, you cannot assume the wall velocity to be same as or or the fluid near the wall will attain the velocity of the wall, this would be somewhat different. So, these boundary conditions will be different, so the magnitude of c 1 and c 2, they will be different, so that is that is the idea.

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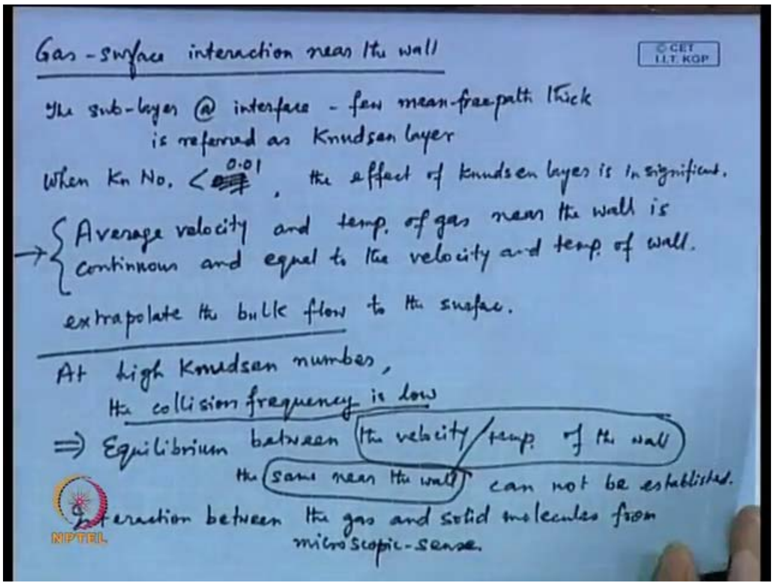

Now, what we need to understand here is that, a gas surfaceI mean I need to focus further on gas surface interaction near the wall, I mean we wewe mentioned this fluid to begas here, because gas will have mean free pathwhich is little higher. And so it is likely that you will be working in this, I mean this this is regime that we are referring to, and you canfor a liquid anyway the mean free path would be less, so applicability of slip boundary condition will be moreimportant. The slip boundary condition would be more important forgas surfaceor or flow of gas through a micro channel.

So, youhave gas surface interaction near the wall, so what we have here is the sub the sub layer the sub layer at the interface at interfacefew mean free pathfew mean free path thick few mean free path thick. This sub layer is referred as (No audio from 06:36 to 06:47) (Refer Slide Time: 06:36) Knudsen layer, this sub layer is referred as Knudsen layer, when Knudsen number is small, when Knudsen number is less than 0.1, less than 0.1 means, less than 10 to the power minus 1.

So, Knudsen number is less than 0.1, the (No audio from 07:22 to 07:37) or or I should say when the Knudsen number is less than 10 to the minus 2, so it should be 0.01, when Knudsen number is less than 0.01, the effect ofKnudsen layeris insignificant. So, what does this mean is,average velocity average velocity and temperature of gas near the wallis continuous and equal to the velocity and the temperature of the wall. So, if this is thecondition, if average velocity and temperature of gas can be, gas near the wall can be considered, if if that is continuous and equal to the velocity and temperature of wall; if this is the case, then you can assumeor then you can extrapolateextrapolate the bulk flowto the surface.

However, when you have this Knudsen number which is higher,at at high Knudsen numberat high Knudsen number the collision frequencyis low, the collision frequency collision means, collision between molecules that frequency is low. So, what this means is, equilibrium between the velocity or temperature velocity or temperature of the wall, equilibrium between this quantity, the velocity and temperature of the wall and the same near the wall near the wall, this is the other quantitycannot be establishedcannot be established. So, equilibrium between the velocity or temperature of the wall and the same near the wall, cannot be established.

So, in that case, I mean this is this is possible only when the collision frequency is low collision frequency is low, when the mean free path is much higher, so mean free path higher that means, the number of collisions is low, so unless molecules they collide. If they collide lot ofI mean, several times then the itwould be easy for the equilibrium to be established, but that is not possible, if you have high Knudsen number or in other words you have low collision frequency. So, there would be some amount of discreteness in this process.

So, in that case, you have to consider interaction betweenthe gas and the solid molecules gas and solid molecules molecules from microscopic-sense not macroscopic, I mean not not the not the not using continuum rather you have to consider the collision, the interaction between gas and solid molecules from microscopic-sense, (()) because the equilibrium has not reached. So, you cannot consider the velocity or temperature of the wall as same for the fluid that is next to the wall.

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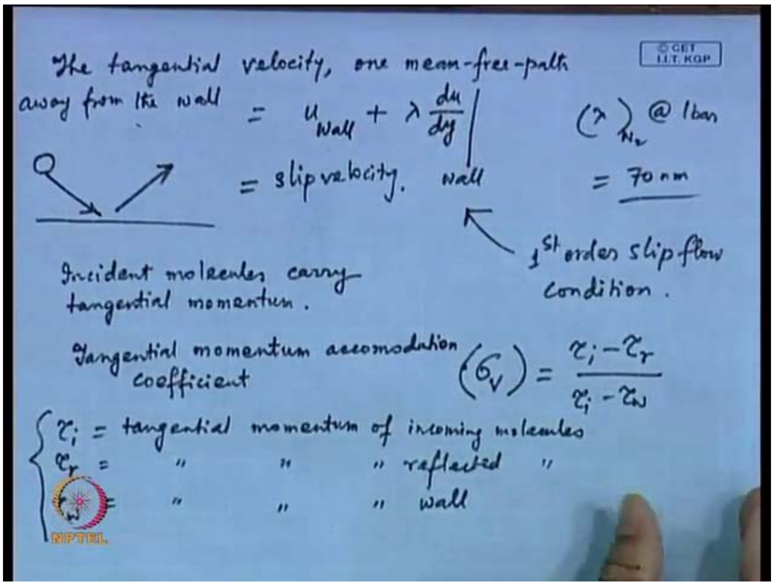

Now, what is done here is, we have to introduce two concepts at this point, one is what we call slip velocity,the tangential the tangential velocity, one mean free path one mean free pathaway from the wall that is equal to is, this is considered as u wall plus lambda d u d yat wall. What are we doing exactly can you guess what whatwhatwhatwhat is happening here, you are assuming that the velocity next to the wall, thevelocity that is attained by the fluid, next to the wall, that in case of a no slip boundary condition, we assume that that is same as equal to u wall.

Now, we are saying that it is not exactly u wall, but little different from the u wall and what is that little difference, so we said that we are not exactly on the wall, but one mean free path away from the wall, what is the dimension of one mean free path? If you,if youI mean I can I can quickly refer for you lambda of nitrogen at one bar pressure that is equal to 70 nanometrealright, so that is the that is one mean free path.

Now, if you consider not exactly the wall, but one mean free path distance that means, 70 nanometre away from the wall and that point you want to know what is the velocity, and what you do is you are assuming, so u wall plus this is the distance away from the wall, d u d y at wall, ideally if you if you expand it there should have been other terms as wellright. So, you are only taking the first order term, and not other termI mean you you are you are perfectly, you are permitted right I mean, if you do not know what is lambda, if I instead of lambda I say h, can you tell me what is the velocity of the fluid, if if the velocity at the wall is u wall, what is the velocity of the fluid at distance h from the wall. And if h is small you can expand it by Taylor series exactly that is what we have done, only thing is we have only picked up the first order term and not the higher order terms. And that is what is referred as first order slip condition, first order this is this is referred as this condition this is referred as first order slip flow condition, first order slip flow condition alright.

And this this is, now this is what we are going to call theslip velocity,this is what we are going to call the slip velocity it is it is not exactly thisthe same; I mean now we will we will tinkle now we will play with this equation further, but essentially first order and why first order you understood, why we are calling it a first order, but this is not a final form of slip velocity, now we will play with this.

Let me let me define couple of quantities here, one thing we must appreciate that if this is the wall and if this the molecule, this comes and hits here and then it gets reflected that is the idea right, we are talking about molecule, collision of molecule, gas molecule with the solid wall, so this is what we are referring.

So, what we can write here is that,incident molecule incident molecules carrytangential momentum, and there is one term called tangentialmomentumaccommodationits quite a long term, accommodation coefficient I have not, I have I know, so many coefficientslong since, so many words in a one coefficient. Now, this is tangential momentum accommodation coefficient, this is given as sigma v that is equal to tau i minus tau r divided by tau i minus tau w; what are these tau, tau i isequal totangential momentum of incoming molecule incoming molecules incoming molecules, tau r is equal to tangential momentum of reflected moleculesand tau w is equal to tangential momentum of wall.

So, if you have these tangential momentums, if these are defined, the point here is that these molecules carries with it some amount of tangential momentum that means, momentum in this direction, and then you have the wall itself may be moving or wall itself can be static. So, if the wall itself has a tangential momentumand incoming and the reflected molecules. So, this is the accommodating these terms, one has a somecoefficient known as tangential momentum accommodation coefficient, which is defined by sigma v.

Now, what we have in this case is instead of writing these as the these as the slip flow velocity the these as the slip these as the slip flow velocityinstead of writing this as slip velocity.

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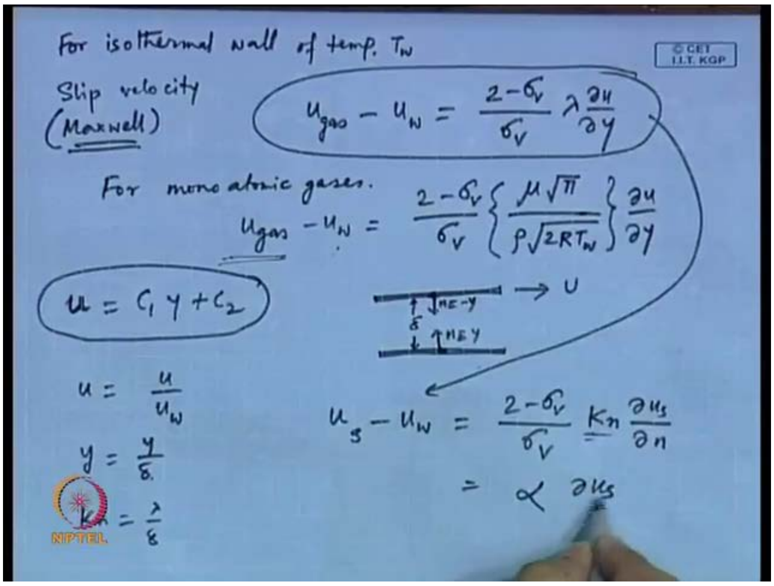

What we write inwhich is which is more, I would say more comprehensive, more moremore detailed one is the expression for slip velocity for an isothermal wall, for isothermal wall of temperatureT w T w, there is a slip slip velocity given by Maxwell.Slip velocity expression given by Maxwell, this gives u gas which is the slip velocity minus u w, which is the velocity of the wallI mean, if you think that wall is fixed then you will consider u w to be 0, no problem 2 minus sigma v divided by sigma v lambda del u del y.

What do we have this is, this came as a first order slip flow condition, using tailor series expansion, then they said that I need to add some accommodation coefficient on this expression (Refer Slide Time: 20:29). And that that factor being 2 minus sigma v by sigma v, this they have shownI mean by some other consideration that is that is why, we we already mentioned name of a scientist here.

Now, more importantly for monatomic gases,for mono atomic gases for mono atomic gasesu gas minus u w, this quantity u gas minus u w that would be equal to that factor 2 minus sigma v by sigma v remain same. However, the lambda the mean free path, that has an expression for mono atomic gases and that expression is mu square root of pi divided by rho square root of 2 RT w, this is an expressionfor mean free path, this is an expression for lambda for mono atomic gases, you need to check the book on physical chemistry, to find out how they arrived at this for mono atomic gases, the expression for mean free path. Anyway that is not exactly under the, this this you can you can figure out, this ishow this expression for mean free path is obtained, check thebook on physical chemistry.

Now, so this is the expression for mono atomic gases that u gas minus u w is there is a factor which has been put there, because of this tangential momentum that incident molecules they bringand then this del u del y, this arising from Taylor series expansion and this is the expression for lambda.

So, if somebody wants to know what is the slip velocity then this is the slip, this is this u gas is the slip velocity, and u w if it is a fixed wall, then it is 0 and for the wall that is moving at a constant velocity u, then u w will be capital U, so this is the expression for first order slip boundary condition given by Maxwell. Now, if we have this information at our, if the if we have this information with us, how do we solve this problem, what was the problem u is equal to c 1 y plus c 2, we said that remain same right.

Navier-Stokes equation for what, we said it is it is basically one plate is fixed and the other plate is moving at a velocity U, capital U in that case the small u the velocity at any location y, y starts from y goes vertically, y is equal to 0 at the fixed plate and it goes up and y is equal to h at the moving plate. So, this is this is this is theboundary condition and this is the so this is the governing equation and the governing equation remains same, whether you have slip or no slip that is what we said.

Now, if we have this as the boundary condition, how will you put this boundary condition inside and come up with the values of c 1 and c 2 that is exactly what you got right, last time what you did, you did the same thing and you have got an c 2 equal to 0 and c 1 is equal to some value,1 by h or u by u bywhat did you get, y is equal to h means u is equal to capital U. So, it is u by h, c 1 is equal to u by capital U divided by h and y c 2 is equal to 0 for no slip boundary condition.

So, now, you have to put in put this this expression to this and come up with the generalized expression for velocity, in case of that micro cuvette flow, so how do you do it? We write here, let us say we write u is equal to u by u w, we try to make this dimensionless, and y is equal to y by deltaI mean, delta is equivalent to h, I mean just because that we have moved from no slip to slip, just because we have considered instead of a macro channel, macro case to a micro case. So, instead of h we arewriting this as delta. So, we have our basic structure remains same that means, we have two plates,one plate is moving at a velocitycapital U and this distance is delta.

So, let us write u as u by u w, I mean do not I mean we are we we should have given some other name, but we are not doing it, I thought we are mature enough to cleavage this, so y is equal to y by delta. Now, in that case and the Knudsen number would be equal to lambda by delta, so if we start from this expression, this is for monatomic gas we do not need toI mean we we, let us write the general one.

Now, what we said is that uu at the or or we call this u s, u s minusu w, u at the surface minus u w which is the velocity of the wall that is equal to 2 minus sigma v by sigma v into, let me write this as Knudsen numberdel u sdel n, what is n, n is basically normal to this plate. So, n is equal to yhere for this problem, n is equal to minus y for this this part of the wall, n is the normal.

So, we can write this further we can and and why are we getting into Knudsen number you understand that,right Knudsen number is lambda by deltaand then we have already y is equal to y by delta and n is equivalent to y, when it comes to this direction n is same as y and when it comes to this plate n is equal to minus y, because n normal is the is against the direction of y. So, thisthis you understand that then then why why you have Knudsen number, because this delta will cancel with this delta alright.

So, instead of writing it as lambda del u del y by delta, we put that delta inside and make it Knudsen number, now if we with or or we can write this as alpha del u s del n.

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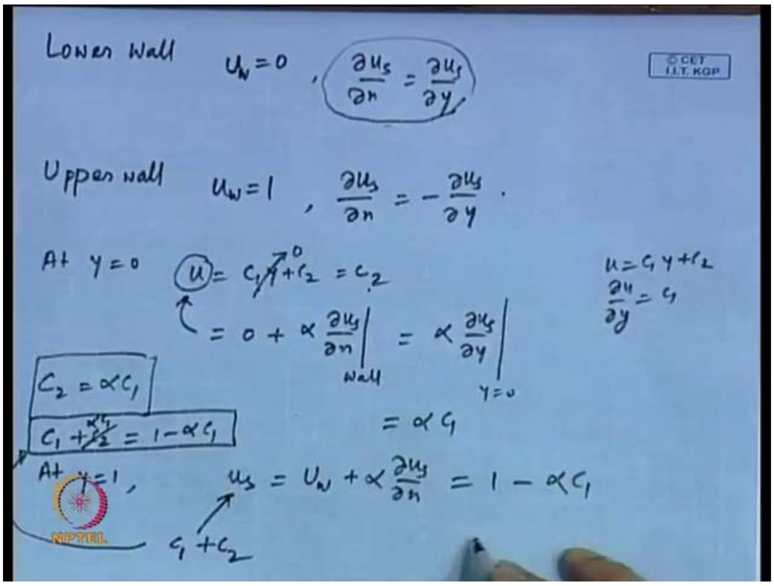

Let me let me write this furtherI mean if Iif I split this into lower wall and upper wall, what do we get lower wall you have u w is equal to 0u w is equal to 0, so what that u w is equal to 0 and not only that, you have del u s del n is equal to del u s del y, because y is y and the normal they are in the same directionalright. On the other hand at the upper wall you have u w is equal to 1, because what is a definition of u, u is equal to u divided by u w.

So, u w is equal to 1 and in that case, you have del u s del nthat is equal, other than that you have del, other than u w is equal to 1, you have del u s del n is equal to minus del u s del y alright. So, these are the conditions one is applicable at the lower wall and the other one is at the upper wall. Now, if you write that at y is equal to 0, if you write that at y is equal to 0at y equal to 0 you are saying that u is equal to, at y is equal to 0, u should be equal to you had c 1 y plus c 2 that is equal to nothing but, c 2 right y goes to 0, so this is nothing but, c 2.

And what is now, the u as per the slip boundary condition as per slip boundary condition this u would be what, this u would bewe need to look into this expression; this u would be u w will go to that side, so it would be u w plus alpha del u s del n u w is equal to 0, the wall velocity condition is 0 (Refer Slide Time: 29:38). So, what do you end up withwhat you end up with, you end up with thisu is equal to 0 plus alpha del u s del n at wallright, one is this we are we arewe are assuming u w to be 0 at the lower wall at y is equal to 0 and on top of that we say, that at lower wall del u s del n is equal to del u s del y. So, using this we are writing this as 0 plus alpha delu s del n that is equal to alpha del u s del y at y is equal to 0 right. And what is this del u del u s del y,if we if we take aif we if we know that u is equal to c 1 y plus c 2 and if you take del u del y that is equal to c 1, so what what do we have alpha into c 1 alright soalpha into c 1.

So, we have one expression that is c 2 is equal to alpha c 1, that is one expression we have in our at our disposalwhat is the other one, other one is that at y is equal to 1 you have u s that is equal to u w plus alpha del u s del n same same thing we are doing, what we have done last time, we are using that same expression u w goes to the right hand side (Refer Slide Time: 31:25). Now, only difference is that here u w is equal to 1 at the upper plate, at y is equal to h number one and number two this del u s del n and del u s del y there is a change in sign, so these are the two things we need to remember.

So, here you will gained up with this is equal to 1 minus alpha c 1right,1 minus alpha c 1 and what is u s (No audio from 32:04 to 32:19) here, in this case u was c 1 y plus c 2 is equal to c 2, here in this case it would be what, c 1 plus c 2. Because, c 1 y and in this place at this place y was 0 at the lower wall, at the upper wall y is equal to 1,y1 because, we have defined y as y by delta, the very beginning, so you have c 1 plus c 2.

So, you have two expression, one is c 2 is equal to alpha c 1 and the other expression is if I if Iif I take this back again, I write here c 1 plus c 2 is equal to 1 minus alpha c 1 this is the other expressionalright. Now, you solve these two expressions c 2 is equal to alpha c 1 and c 1 plus c 2 isI mean solving does not it is no big deal, because you you can you can put this c 2 instead of c 2 you write simply alpha c 1, instead of c 2 you write alpha c 1, so everything in terms, so we basically eliminate c 2.

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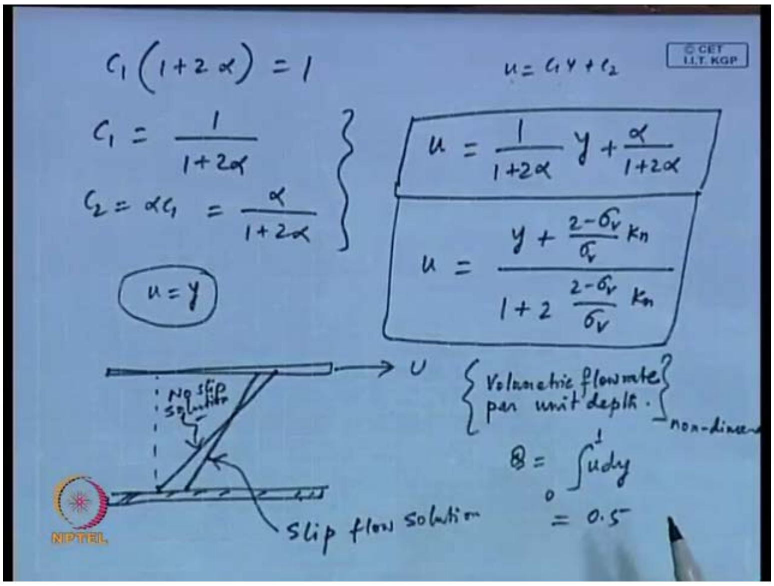

And so what you end up with in that case is I can write hereas c 1 into 1 plus 2 alpha that is equal to 1, c 1 you bring all the c 1 to the left hand side, and so you get c 1 into 1 plus 2 alpha is equal to 1 oryou get c 1 is equal to 1 by 1 plus 2 alphaand c 2 we had alpha c 1 that means, equal to alpha by 1 plus 2 alpha. So, earlier, we had what, we had c 2 is equal to 0 and c 1 is equal to, we had capital u divided by h.

But, now we have some other quantities, so if somebody now wants to write what is expression for u, you will be writing u is equal to 1 by 1 plus 2 alpha into y, u is what c 1 y plus c 2 right, that was the expression, for u general expression. But, now you are putting this c 1 and c 2, so u is equal to 1 by 1 plus 2 alpha y plus alpha by 1 plus 2 alpha, that is the c 2, that is a constant.

So, this is the expression for u considering slip flow boundary condition,you can you can you cansimplify this further and probably the one, because alpha is your creation, alpha is notsomething, which isI mean alpha is basically some variable you clubbed together.

So, if you if you remove them you get, because originally sigma v is somethingwhich is, whichresearchers were working in thisin this area they understand, so this divided by 1 plus 2 into 2 minus sigma v by sigma v into Knudsen number. So, this is probably the expression that is(()) basically another form of this expression.

So, what was a continuum flow u is equal to y, corresponding continuum flow expression was u by capital U is equal to y by delta or y by h and in dimensionless form it is u is equal to y, and in dimensionless form the slip flow condition gives u is equal to this this expression. And this expression is meant for then what, meant for this micro cuvette flow, you have two plates the upper plate is moving at a constant velocity, and the lower plate is fixed, so this is this is how you do it?

Now, if somebody wants to know what is the, now now if you if you if you want to draw how this how this whole thing looks, this is the plate that is moving at a constant velocity u, and this is the plate that is that is fixed. So, if you have a slip,if you if you have no slip boundary condition, you can expect this to be the velocity profile right, velocity is 0 here and velocity is capital U here,that is that is the no slip boundary condition.

Here also since, we are retaining this u is equal to c 1 y plus c 2 form that means, the velocity profile in this case will also be linear can somebody guess then what would be the form, it will not be 0 here definitely, so it will start from here and it will end before this, so it would be it would be like this (Refer Slide Time: 36:50), so this isthe slipflow solutionand this is the no slip.

Now, if somebody wants to know what is the volumetric flow rate per unit depth,depth is perpendicular to the paper, if somebody wants to known the volumetricflow rate per unitdepth, and if somebody wants to know the non-dimensional, this in non-dimensional form; then what he will do is you will find this qrunning from 0 to 1 u d y, that is the expression, if somebody wants to know that you have one plate fixed other plate is moving.

Now, the this fluid that ispushed downstream, what is the volumetric flow rate per unit depth perpendicular to the paper, that thatcommonly we try to find out and here what we find is if we if we want to do it in a non-dimensional form, it would be integration of 0 to 1 u d y.

Now, it would be your task when you go back after the class integrate this between 0 to 1 u d y and see that these value is equal to 0.5 and check the same thing with the continuum solution, and you will find it is the same value you get for continuum solution as well, so that that you need to you need to does it yourself.

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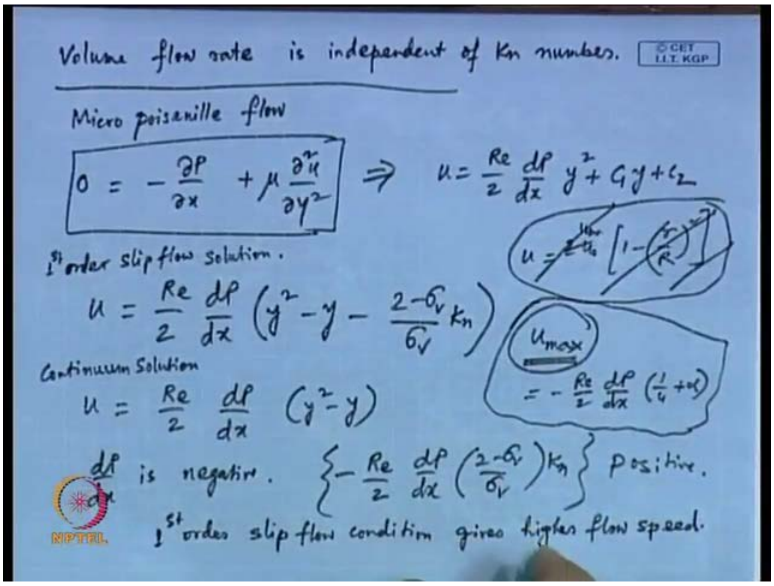

So, the conclusion that we draw is that volume flow rate volume flow ratevolume flow ratehere is independent of Knudsen number, this is very importantI mean you have from continuum flow you found out some volumetric flow rate, you have(()) plate you have moving plate and you found some volumetric flow rate. What this says is even if you did all these things first order boundary condition etcetera, the volume flow rate remains same, and so whatever you had from continuum solution that was good enough, so then as far as the volumetric flow rate is concerned.

So, this is not, this is independent of Knudsen number, this this is I think is some very important you need to remember. Now, this is for a micro cuvette flow similarly, you can have something called a micromicropoiseuille flow; this is notthis should be pronounced properly this should this should be pronounced properlyand thisI mean Iwe need to check the pronunciation.

Now, this micro micropoiseuille flow micro poiseuille flow flow this, if somebody wants to wants to solve the same thing that you have done here, for micro cuvette flow instead of that, if you do it for a flow through a tube, flow through a capillary. Andinstead of no slip you want to go for slip boundary condition, then what kind of expressions you end up with that I would like to, I mean I would I would notsolve it from the way we have done it here, what I will do is I will just give you the final expressions, and that that that is that is all I would like to say here.

Now, the Navier-Stokes equation in this case, would will be will be settled tothis form (Refer Slide Time: 41:16) this formand so the solution here is, Reynolds's number divided by 2 d p d x that is the pressure gradient y square plus c 1 y plus c 2 this is this is the form of velocity. I meanyou remember, what was the what was the velocity we have been working with, parabolicvelocity profile etcetera, there we havesimilar quantity, we havesomething into 1 minus r by R whole square that is something we call this as 2 u 0 sometimes we call this u max.

So, this is this is this is the type of form we have, if you want to write in a generalized manner instead of r, if we write it in y we end up with an expression something like this. Now, here if you if you do this same exercise with slip flow boundary conditionI meanif you if you bring in the concepts that we discussed here, you will end up with an expression which looks like this (Refer Slide Time: 42:35) (No audio from 42:35 to 42:53).

And the corresponding continuum solution is (No audio from 42:56 to 43:07), so this is the continuum solution, and this is the first order slip flow solution. So, this is the first order slip flow solution and this is the continuum solution, one can one can make some note here is thatd p d x is always negative is negative.

So, if d p d x is negative then one mustone has to havethis quantity R e by 2 d p d x into 2 minus sigma v by sigma v into Knudsen number that means, the additional term that you have, because of first order slip flow solution. Now, this is negative means minus of this quantity, this would be positive.

So, what that means is that, these quantity this this extra term that you have minus R e by 2 d p d x into this term that is positive that means, first order first order slip flow condition giveshigherflow speed, that is one conclusion you draw here, also in case ofin case of a poiseuille flow, in case of a flow through a capillary, what you need to, I mean what would be another thing is this u max. In case of a micro cuvette flows this was not important, but flow through a capillary you know that at the centre the velocity is maximum and all kinds of things.

So, you have a similar exercise you can do with u max as a matter of fact you can you can obtain this u max as equal to minus R e by 2 d p d x into 1 by 4 plus alpha one can one can one can seethis, alpha is of the same meaning as we had done earlier, in case of a micro cuvette flow we had a definition of alpha. So, you can one can come up with these thesethese expression, one can come up with this u max expression. So, these all these exercise that we do for for macroscopic flow, these exercise can be done with this first order slip flow boundary condition. So, what what we said at a very outset I would like to go back once again, becauseafterI mean, today we are going to end this discussion on slip flow and we will move to another topic.

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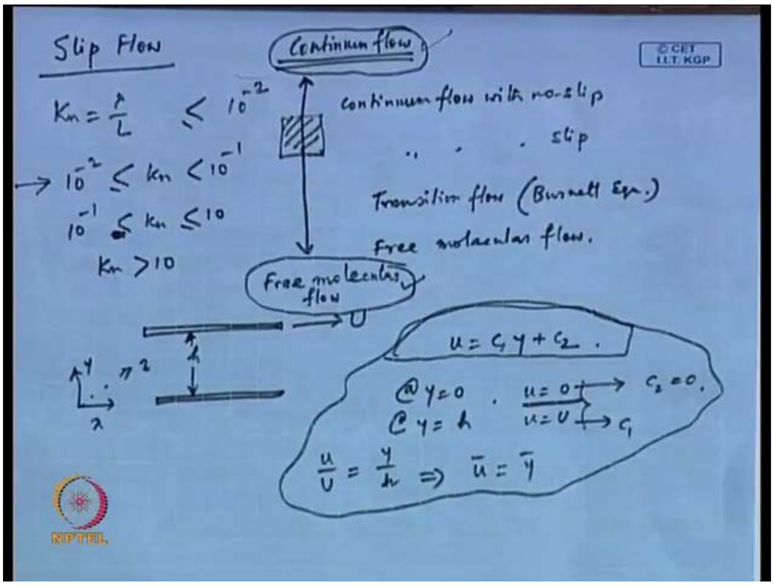

What I would like to see at the very, what what I already said at the very outset is that there is this continuum flow with no slip, then there is continuum flow with slip and then there is transition flow and then free molecular flow. Now, this free molecular flow is ideally what you should be considering andcontinuum flow is at the other end. So, if you look at the entire spectrum on one end of the spectrum it is the continuum flow, and the other end of the spectrum it is the free molecular flow, which is the collision between molecules and molecular dynamics.

However, this is computationally, it requires lot of effortI mean by if you if you want to track say a 1000s of moleculesfor say hoursI mean computationally just tracking the molecules, tracking the velocities after each and every collision its itsits it is a tremendous task. So, in fact continuum flow is basically you make some assumption and then youyou are you are you arethe process of arriving to the solution is much simpler, but you make certain assumption in case of continuum flow.

So, you are in between these two (()) these two bounds, so when youwhen you work with macroscopic fluid mechanics you are in continuum flow, and when you are in molecular dynamics, you are in free molecular flow. Now, where this this slip boundary condition or whatever we discussed today as first order slip, that state somewhere; that is basically what we call a make do approach, I mean you haveI mean you know that you are not doing the right thing, the rigorous thing would be free molecular flow or if you can makethe other rigorous thing would be continuum flow, based on which you are writing this Navier-Stokes equation.

Now, this slip boundary condition here you are kind of you know that you neither, you are you are in a regime where continuum flow assumption cannot be taken; however, you do not want to invest that much of effort in getting into the free molecular flow. So, you are somewhere, so you you come up with a with an approach which is more more sort ofpractical, you come up with an approach which iswhich where you do not require that much of computational time, and at the same time you do not a leave out all the understanding of continuum flow.

So, this is definitely this is not 100 percent rigorous however, this gives you thethis gives you the right I mean I mean by balancing these,you can you can you can learn lot of theselot of lot of, you can get lot of insight into this kind of flow. So, today I would like tostop here, basically today today I would like to (No audio from 49:46 to 50:07) from the next class, what I would be doing is I will be talking about something called a micro structured reactor.

TherewhatI will I will essentially tell you the, how we can simplify variousfluid flow and heat heat balance equations, because in a I remember, when I introduced this micro structured reactor, I mentioned about thishoneycomb type structure, you might havealready you you might, you can recall it is like honeycomb structure instead of a random packing, randomly packed bed what we will have here is very specific, specificallymachined channels.

And these channels will be acting as a reactor andas you, so as the fluid flows through these reactors they will have,there there will they will have the fluid flow issues, they will have the heat transfer, heat transfer issues and they will have this reaction going on simultaneously. So, how toI mean of course,you can you can very well say we can start from first principle pick up the best model, that we have infrom CFD and solve this, but we should, what we have to do is we need we need some approximate method, some some method to quickly come up with some solution.

So, that we can compare various geometriesI mean we should notwe are talking about thousands of such channels running parallel, so theI mean people haveestablishedsome method touse a best of everythingI mean, basically it is it is partly a CFD model. But, not as rigorous as a CFD model should be some amount of approximation they put in there, and they come up with the solution and then try then they try to find out if you would have gone for a rigorous CFD model, how how much we differ from the actual solution.

So, that exercise I will get intoin the in the next class, I think I will require just one class for that and beyond that point, I will be talking aboutimmiscible flow through micro fluidic channels, flow of bubbles, droplets. We have two phases which are immiscible, and if you have a if you have that kind of flow through a micro channel, what what is the result. So, that is something which I will be taking up next.

So, next class that means, tomorrow's class we will be talking about this microstructure reactor and I will identify quickly, what all assumptions you can make from the most rigorous CFD modelto get a quick solution. And from next to next class we willwe will be getting into the immiscible flow through micro channel, and that that is going to be the lasttopic very likely, that is all I have for today, thank you very much.