Adiabatic Two-Phase Flow and Flow Boiling in Microchannel
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Lecture - 20
Theoretical Analysis of Two Phase Flow in Reduced Dimensions (Contd.)

Hello everybody. So, we continue with the discussions of finding out the hydro dynamics of flow using the homogeneous flow modal.

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For adiabatic and no flashing

$$-\frac{dp}{dz}=\frac{G_{TP}^{2}\left[\frac{2f_{TP}}{D}\left(v_1+xv_{12}\right)-\left(v_1+xv_{12}\right)\frac{1}{A}\frac{dA}{dz}\right]+\frac{g\cos\theta}{\left(v_1+xv_{12}\right)}}{1+G_{TP}^{2}\left[x\frac{dv_2}{dp}\right]}$$

For adiabatic flashing x=x(p)

$$-\frac{dp}{dz}=\frac{\frac{2f_{TP}}{D}G_{TP}^{2}\left(v_1+xv_{12}\right)-G_{TP}^{2}\left(v_1+xv_{12}\right)\frac{1}{A}\frac{dA}{dz}+\frac{g\cos\theta}{\left(v_1+xv_{12}\right)}}{1+G_{TP}^{2}\left[\left[x\frac{dv_2}{dp}\right]+v_{12}\frac{dx}{dp}\right]}$$

For general case, both phases compressible & x=x(h,p)

$$-\frac{dp}{dz}=\frac{\frac{2f_{TP}}{D}G_{TP}^{2}\left(v_1+xv_{12}\right)+G_{TP}^{2}\frac{v_{12}}{h_{12}}\frac{dh}{dz}-G_{TP}^{2}\left(v_1+xv_{12}\right)\frac{1}{A}\frac{dA}{dz}+\frac{g\cos\theta}{\left(v_1+xv_{12}\right)}}{1+G_{TP}^{2}\left[x\frac{dv_2}{dp}+\left(1-x\right)\frac{dv_1}{dp}+v_{12}\left(\frac{\partial x}{\partial p}\right)_h\right]}$$

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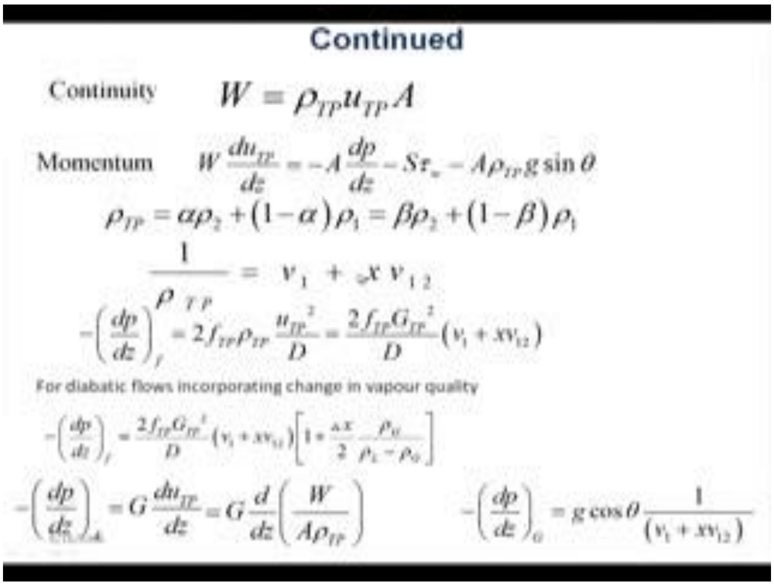

As I have already mentioned the homogeneous flow modal it is given by this particular equation for different cases this is the general equation, when both the phases are incompressible we can just use this equation and we found out that only was to find out the 2 phase friction factor.

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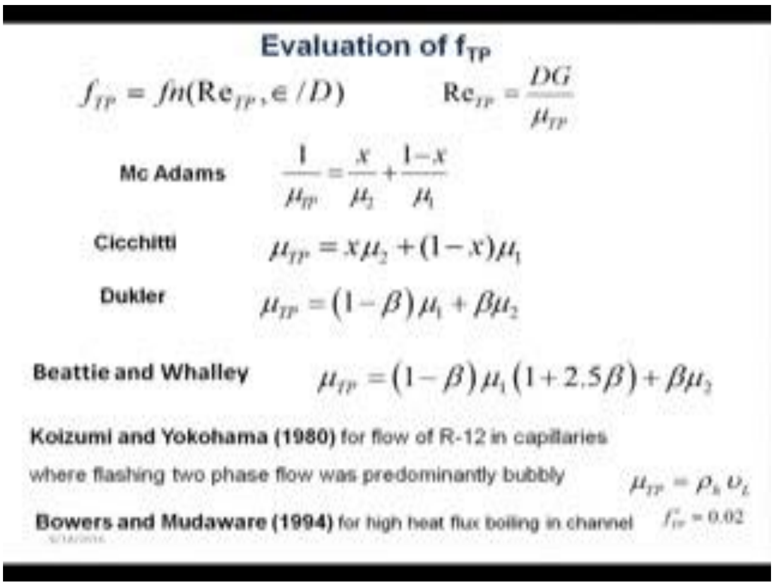

So, there are as I had mentioned there are 2 ways of estimating the 2 phase frictional pressure gradient.

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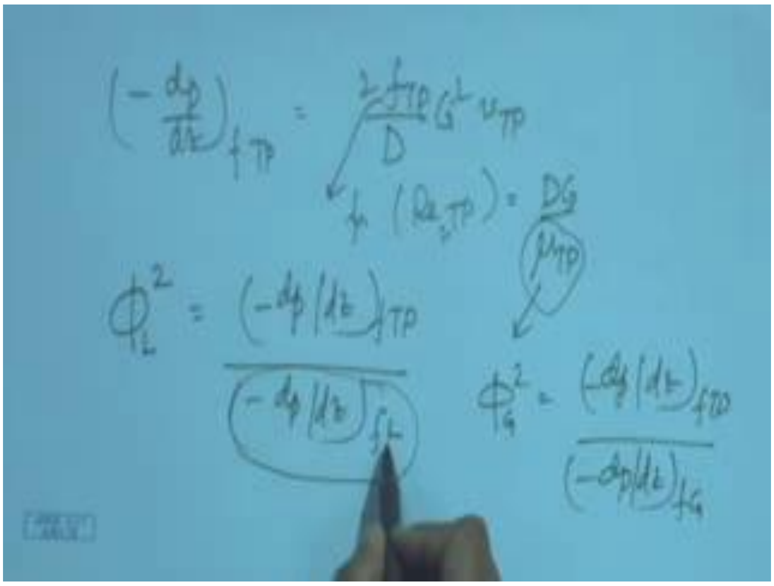

One particular way was to express it in the form of just the way we express single phase pressure gradients in the same way it can be expressed as 2 f TP by D G square v TP, this is one particular way and here we find out f TP where f TP can be defined in terms of Reynolds number Re TP right

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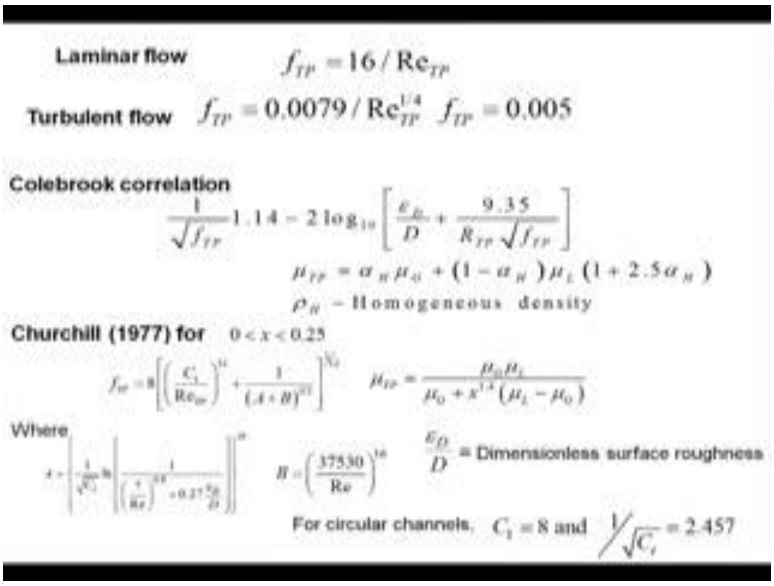

the other way which is quite commonly done for macro systems is that one more thing I forgotten to mentioned which I should be mentioned that well its very good that you can find out f TP in terms of ReTP and then you defined for ReTP you need to find out mu

TP and for finding out mu TP there are large number of expressions, but once you are found out ReTP in order to find out f TP from ReTP, we need some particular relationships.

Now, we all know that for laminar flow rather for 2 for a single phase for laminar flow we have this equation for turbulent flow we have this either we can express it in a blushes type of correlation or we can take a constant 2 phase another constant friction factor. The same thing is adapted for macro systems as well, in those cases also if it is a, if ReTP from a suitable average mu TP is less than 2100, we use this equation greater than twenty one hundred we either use this equation or we adapt a constant value. But in micro channels it is very important for us to realize the thing which had mentioned in my last to last class was that usually we find that for macro systems and even for liquid flow in micro system, the friction factor is independent of the or rather it is not expressed in terms of the relative pipe roughness for laminar flows.

We take into account the epsilon by d phi factor will for turbulent flows on the other hand when we have come down to 2 phase flow in micro channels what we realize we realize that flow as per Reynolds number the way it is calculated and the critical Reynolds number is decided the flow is mostly laminar in micro channels, but wall effects are extremely important this have been discussing since the beginning of the of this lecture series. So, therefore, definitely a proper representation of the friction factor in 2 phase flow through micro channels, it cannot be represented by this particular expression. So, on the contrary people have try to use the expression which has been proposed by Churchill for single phase flows just by replacing your single phase Reynolds number with the 2 phase Reynolds number and we f TP, this particular equation this is applicable for the entire range of laminar turbulent and transition and this is preferred as compare to this particular equation.

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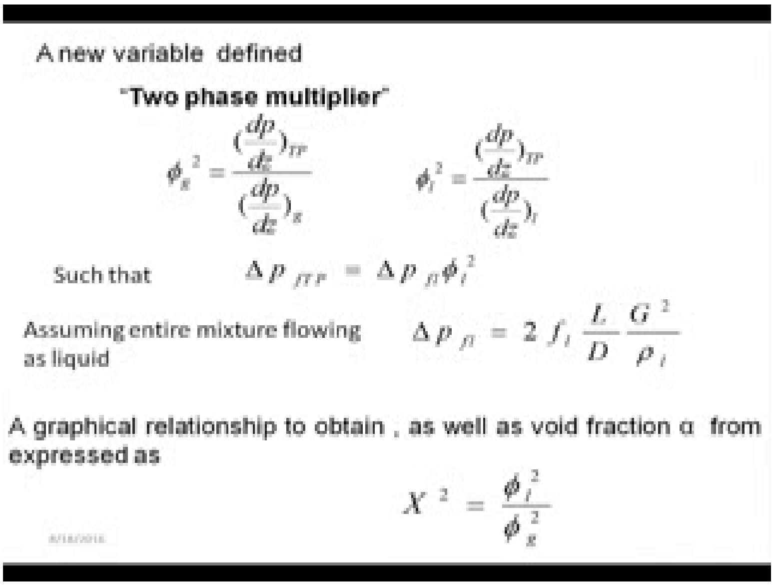

You can also use a Colebrook equation, we find that for both the equations they take into account a epsilon by de factor and therefore by using either of the equation we can account for the relative roughness in laminar flow well. So, this was a regarding to finding out the fix to 2 phase friction factor and then estimating the frictional pressure gradient; well there is another way as I was telling this is very conventionally used for gas liquid all liquid flows in macro systems is to defined a 2 phase multiplier phi square and this phi square it is basically the ratio of the 2 phase frictional pressure gradient to the ratio of the single phase pressure gradient.

Now, this single phase can either be a liquid or a gas, if gas liquid mixture is flowing in a pipe. If we consider this as a liquid then this is denoted as phi l square and if, we consider this as a gas then we make it phi g square right now, here I have got one particular point of caution I have estimated the I can estimate the single phase frictional pressure gradient on the assumption that the liquid which was flowing in the pipe is now flowing alone in the same pipe or in other words what was the amount of liquid which was flowing in the pipe amount of liquid which was flowing was g in to 1 minus x.

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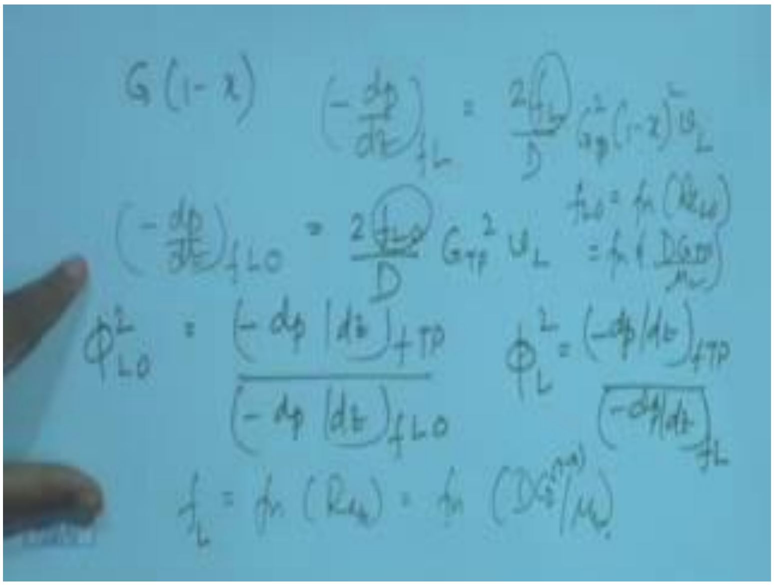

Now, I assume that this G in to 1 minus x amount of liquid is flowing alone in the pipe, as a result of which the frictional pressure gradient for the liquid phase flowing alone is given by 2 f L by D, G t p square in to 1 minus x square, this is the effective mass flux of the liquid portion in to VL right.

I can also assume that the entire gas and liquid mixture is flowing alone in the pipe, where in this particular case I would like you to note that when the entire gas plus liquid mixture is flowing alone in the pipe. It automatically appears to one that it just liquid flowing in the pipe and we are trying to find out the frictional pressure gradient. So, naturally for does it imply? It implies that since the same liquid the same properties are flowing the frictional pressure gradient should be the same no matter.

Whether the only liquid portion is flowing alone on whether the entire mixture is flowing through the pipe if the liquid portion is flows then its g into 1 minus x great fraction which is flowing where as if the entire mixture flows it is the g fraction, which is flowing right now we find that although the same liquid is not contact with the pipe wall, but nevertheless the expression of frictional pressure gradient changes for the 2 cases for one particular case we have this expression for the other particular case we have this particular expression.

And just note. So, accordingly if my single phase friction rather single phase pressure drop is liquid and gas flowing alone in the pipe, I defined phi LO square which gives me d p by d z frictional 2 phase by d p by d z frictional entire mixture flowing as liquid in the pipe and if the liquid portion is flowing then, my correction factor will take in to account my frictional pressure gradient when the liquid portion is flowing alone in the pipe for this particular case this is the expression for this particular case this is the expression.

So, from this expression immediately you find the differences the mass fluxes are different, but along with that try to understand or try to notice. If you observe this 2 expression you will find that even I have denoted the friction factors in a different way in this case it was f L and this case it was f Lo what should these 2 be different both the cases say any liquid or same water is flowing through the pipe mass fluxes are different, but if the mass fluxes are different should the friction factor be also different?

Let us think about it what is friction factor can you tell me this is a function of Reynolds number what is Reynolds number it is it can be expressed in this particular way, if it is liquid Reynolds number then it is going to be the liquid viscosity and accordingly G has to be defined. Now suppose I defined the f L in this particular case then naturally should be a function of R e l and then what is this R e l? This should DG in to 1 minus x by mu l on the other hand, if I am dealing with the entire mixture flowing as liquid then in this case f LO this is a should be a function of the entire mixture flowing as liquid or in other wards this should be a function of DGTP by mu L is not it.

So, what you get, we find out that the single phase friction frictional pressure drop it because for the 2 cases the mass fluxes are different it not only effects the mass flux term here it also effects the friction factor because, friction factors are finally, they are function of Reynolds number which also involves the mass flux.

So, therefore, this must be take kept in mind when you are trying to derive all those things 0.1 of advise for my side is that when you are deriving this particular expression start from the basics and do not jump steps that is going to be much more convenient for you right.

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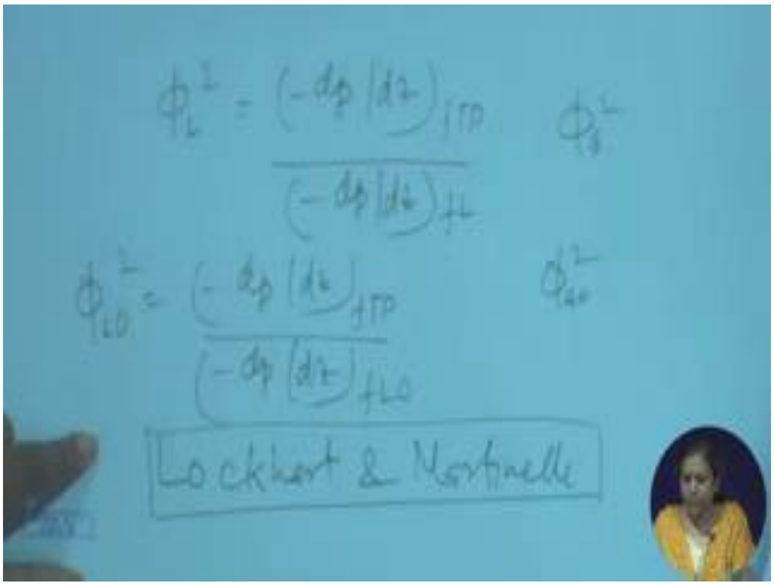

So, therefore, we find that we can defined in all flow 2 phase multipliers one is phi l square which I have already written down with the liquid portion flowing alone in the in the pipe the other is the entire gas liquid mixture flowing as liquid through the pipe right similarly we can define phi g square and phi 0, square now remember one thing. When we are dealing with adiabatic 2 phase flows with more or less comparable proportion of the 2 phases we go for phi l square and when we are dealing with change of phase where at the inlet we have a saturated or sub cooled liquid or may be a saturated vapor and as it is flowing through the pipe change of phase occurs due to some amount of heat flux or may be due to some amount of pressurization then in that case its often more convenient to use the phi square yellow part.

Now, how this it is very good that I could define, I can find the 2 phase friction factor in terms of single phase friction factor provided I know phi l square. So, what if what is rather how to find out phi l square now people have found out rather the first person who had suggested this a relationship to find out the 2 phase multiplier is known as Lockhart and Martinelli. This was a the 2 researchers they are quite well known and we refer to them very frequently they obtained a relationship they found out that phi l square or phi g square it has some particular relationship with a parameter which they defined as x square which is nothing, but sorry it is nothing, but phi l square by phi g square.

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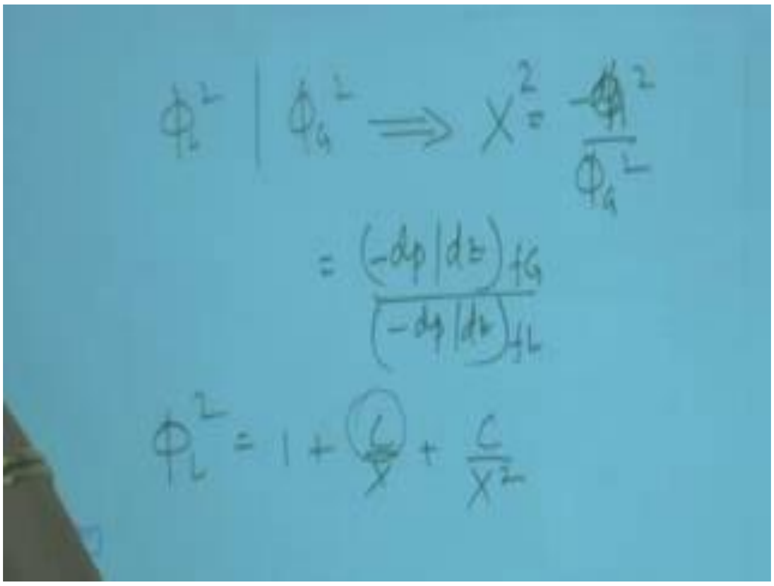

So, therefore, for does it reduce to it reduces to the ratio of the single phase friction factor of the gas and the liquid and you find this is a known quantity you can also find it out from even without doing experiment, you can find out the single phase friction frictional pressure losses right and people have found out particularly Lockhart and Marginally was the first person who found out that the relationship between these 2 should exist.

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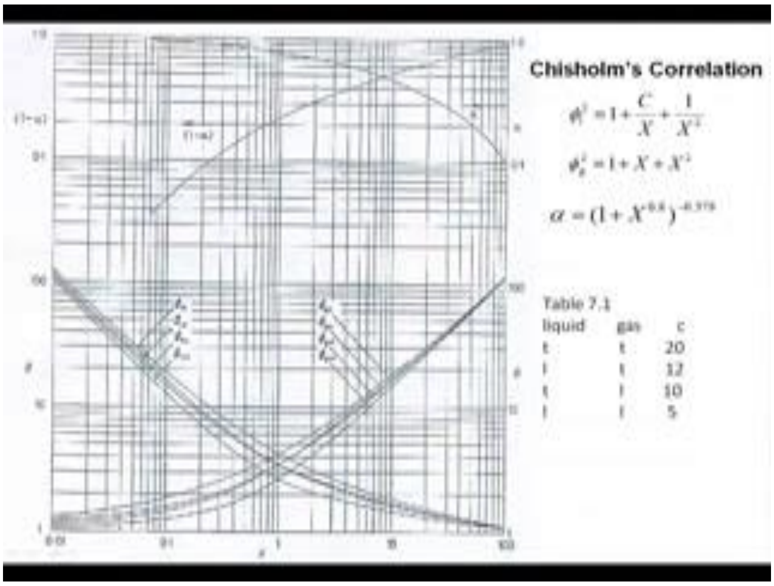

He proposed a graphical relationship of this form where you can find out that this relationship they had they had proposed four sets of graph depending upon whether the liquid and the gas were in turbulent flow or in laminar flow.

So, depending upon this they suggest it four different graph these were the graph for phi l square and these was the graph for phi g square right subsequently Chisholms he developed one particular analytical or he proposed an analytical expression to find out phi l square from x and the relationship. Which was proposed it is a very well known relationship I would like to write it down it express is phi l square from x as a function of some particular empirical constant c, where different values of c were proposed depending on whether, the liquid and the gas are in turbulent flow or in laminar flow you would realize that this particular combination with liquid turbulent and gas laminar is usually very rare and for multi rather for 2 phase flow in micro channel we often come across the liquid gas both laminar phase where c is 5 or in other words the liquid laminar and the gas turbulent where it is 12, but usually we come across this particular rather this is much more applicable for micro channels.

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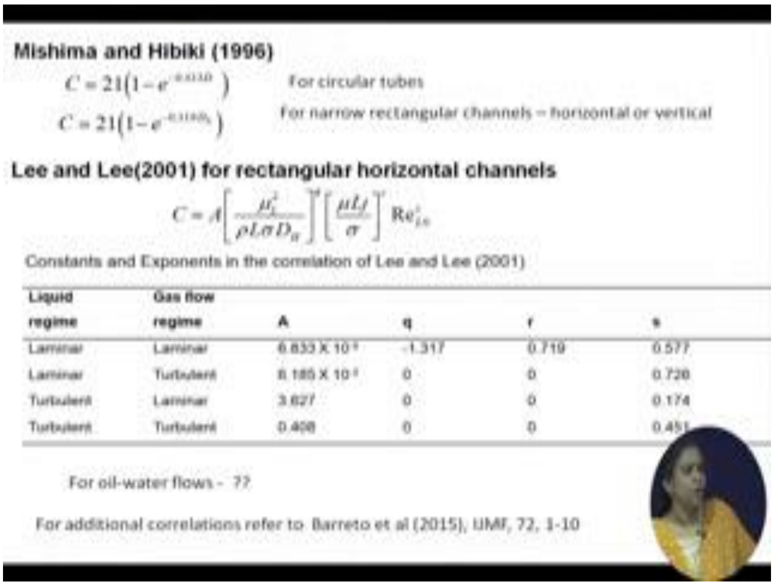

Now, other than this what people have done is they have found out that more than Chisholms correlation it is not always applicable and some other correlations are much more applicable for micro channels now very commonly used correlation again which has been suggested by Mishima and Hibiki there is a slight difference in the constants for circular tubes and narrow rectangular channels with the very less gap between the 2 phases and the important thing again, I would like to say it is just important to remember the functional form of the relationships rather than the exact constants, in case we ask question on this in your assignment or in the in the final examination then this relationship will be provided few expressions you should be remembering. For example, the value of c is important the just (Refer Time: 16:50) and the (Refer Time: 16:53) mu t p were important a few of this particular relationship it we should be remembering.

So, therefore, this is the very well known relationship and the important part of this is this suggest that is c actually it decreases with decrease in diameter is not it. So, this is what is important in this particular expression it shows that c actually decreases with decrease in diameter and. So, therefore, it might suggest that suppose we go for very small channels and then in that case it can happen that c can almost become equal to zero which implies that the 2 phases they are flowing side by side with perfectly laminar type of flow and outside I would like to tell you that the reduction of c naturally implies that the pressure gradient it decreases with decrease in phi diameter and that is for our experimental results also suggested.

There are much more complicated relationships to find c and they have been provided definitely you do not need to go through all this relationships, it just let you know that well other relationships also exists, but there is one things which I would like to like to discuss.

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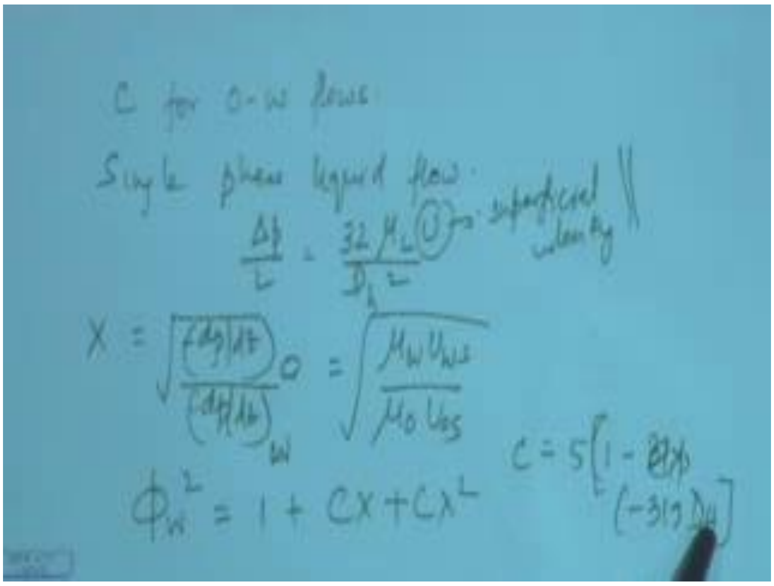

Before, I move on to the next topic that is the expression of c for oil water flows. Now for oil water flows we find that if we considered the single phase liquid flow for laminar cases what do we get we get delta P by L, this is nothing, but equal to 32 mu L into U by D h square, for non circular channel where D h is the hydraulic diameter. So, in this case delta p is the pressure drop over the length L, mu is the dynamic viscosity and U is the superficial velocity of that particular fluid.

I have something to say about these particular terms of superficial velocity before I end this class just remember this particular term. Now in this case, if you write down x which is root over of minus d p d z of one phase divided by minus d p d z of the other phase, so for gas liquid cases it was gas it was G here and in this case it was l here. So, for this particular case it should be oil here and it should be water in this particular here and therefore, this automatically it gives mu w U w s by mu o U o s root over and what people have suggested is, for this case the 2 phase multiplier for phi w square has been expressed as 1 plus c x plus x square where c has been obtained again in the form either Chisholms correlation is good, but the better correlation is which again gives c as a sorry exponential minus three one nine in to DH.

So, in this particular expression c was given. So, therefore, it shows that for larger phi diameter the value of C reduces to the Chisholms correlation and for smaller phi diameters we find that C is more or less a rather it is an exponential function of the hydraulic diameter well there are several other relationships also. For example, people have also suggested that for slug and annular flows, but you did not remember.

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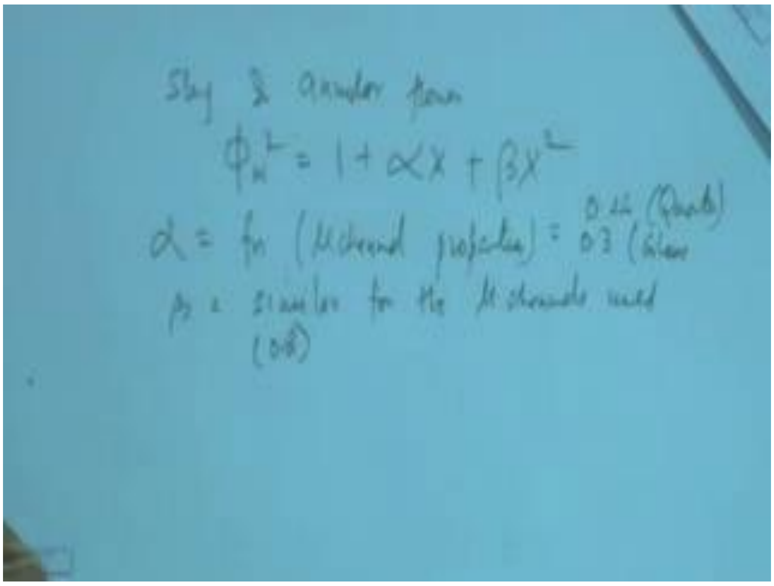

So, many things it is just to show you the innumerable effects, which people have put behind this just to get a suitable expression to find out the pressure gradients where it was observed that alpha is a function of micro channel properties and beta it was more or less similar for the micro channel used. So, this was observed to be 0.26 for the quarts micro channel used by Salim and 0.3 for the glass micro channel and this was more or less it was 0.8 for both the micro channels anyhow.

So, these things the important thing which have wanted to tell you among all these things were that first that first thing is the conflict of 2 phase multiplier and phi l square and phi l o square are different and then, how phi l square or phi g square is related to x square and it also important to know that when we are dealing with boiling 2 phase flow or convincing 2 phase flows when a single phase is start flowing and then, changes its phase then it is usually use phi l o square when a 2 phase mixture is flowing on a adiabatic condition with comparable preposition of the 2 phases we use phi l square and usually this is related to x square that the functional form as shown here.

And usually this functional form it is not always very good for micro channel. So, modification of this functional forms incorporating the hydraulic diameter has been used for the case of micro channel well I would like to say that apart from using c there are also large number of other type of correlation which have correlated phi l square with x and there are different type I would not be going to details and I am already running out of time, but if anybody is interested that person can referred to the paper of Barretoet al of 2015 and go and look for the correlation themselves.

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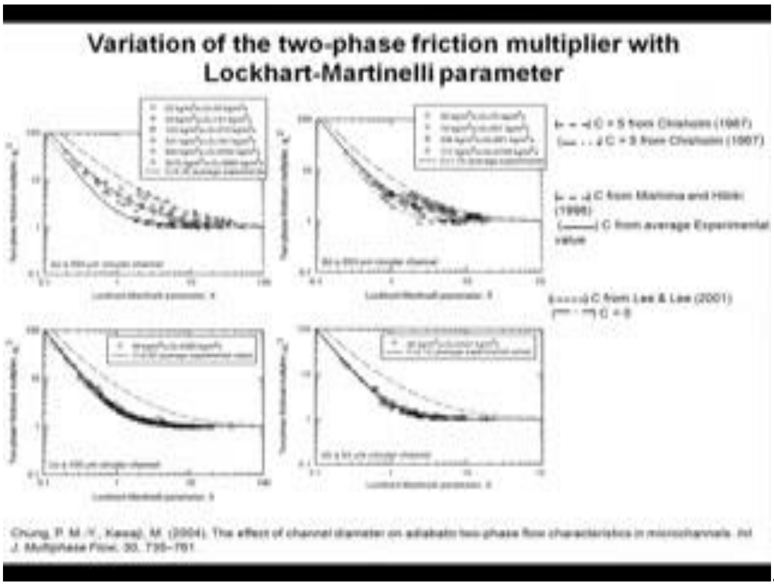

Now, if we use if we four people have done they have try to express and then they have try to plot the 2 phase multiplier as a function of Lockhart Martinelli parameter for again that four micro channels about which, I have been discussing and this particular at this particular graph it shows that when the 2 phase multipliers have plotted, if you observe carefully you find that well the Chisholm correlation is not bad for the larger micro channels, but if you observed closely you will find that, a mass flux effect is very evident in this micro channels in the larger micro channels.

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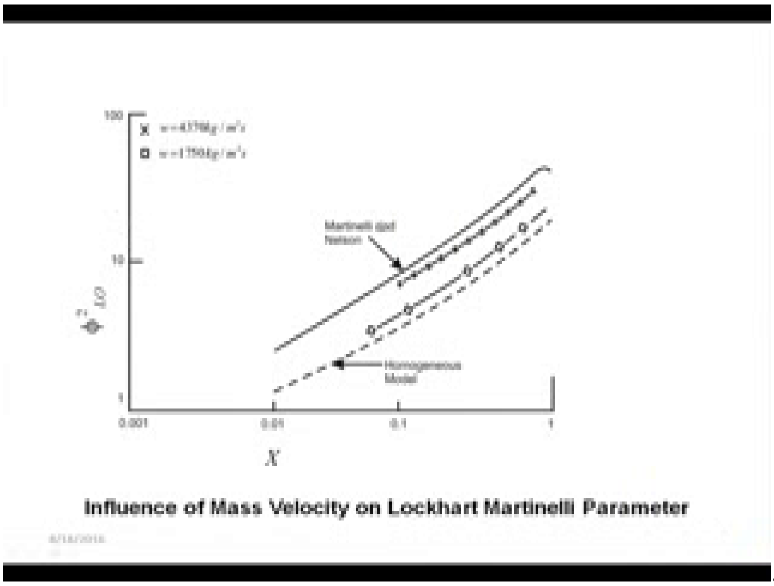

Well I would like to tell you that such a mass flux effect has also be reported for larger channels and then again several problem researchers have try to incorporate the mass flux effect and give a modified correlation between phi l o square in x we find that such a mass flux effect is very evident in the case of larger micro channel and therefore, this implies that single value of c is not always very accurate in order to predict the 2 phase multiplier over the entire range of phase velocities on the contrary. When, we come to smaller channel we find that the mass flux effect is almost not significant else not at all important and all the points have collapse to a single graph in this particular case.

So, therefore, from here we can understand that there are certain things that you understood first we see, decreases as channel diameter gets reduced number one number 2 the mass flux effect tends to disappear as we go for smaller micro channels which again it implies that since smaller micro channel because of the case of a highly laminar flow of gas and liquid with minimal momentum cabling between the 2 phases. This possibly happens and well with this I have come to the end of the homogeneous flow pattern and I would like to tell you that again I would like to summarize it in this particular way that the homogeneous flow pattern.

It is very frequently used for micro channels. Firstly, the only problem of using homogeneous flow pattern are 2 the first thing is to find out the acceleration pressure gradient because, all though it might not be important for adiabatic flows in micro systems it is quite important in this case and when we have boiling to phase flows naturally your acceleration pressure gradient becomes much more important the other thing is to in order to find out the friction pressure gradient there are 2, 1 of the 2 approaches are used either you defined a suitable 2 phase friction factor or you define a 2 phase multiplier and try to find out the 2 phase multiplier from some particular relationship were Lockhart and Martinelli parameter which is a ratio of the single phase pressure drops.

And if you are dealing with air water or adiabatic flows with comparable prepositions of the 2 phases we would adapt phi l square. If you are dealing with boiling 2 phase flows we would like to adapt phi l o square and I am also shown you how phi l square and phi l o square all though both of them, refer to single phase frictional pressure drop for the liquid, but they do not lead to the same expression or they not identical because mass fluxes are different for the 2 cases for phi l square. We assumed that a liquid portion of the pipe is flowing alone now and for phi l o square we assumed that the entire mixture is flowing as liquid.

So, with this I complete the homogeneous flow modal and in the next class, we will be discussing some amount rather 2 types of flow pattern based modal one is the drift flux modal which modifies the homogenous flow modal to account for the slip between the phases and then, we go for the slug flow modal. So, with this I would like to end today's talk.

Thank you very much.