Multiphase Flow
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Lecture No. # 24
Separated Flow Model - Estimation of Friction Pressure Drop and Void Fraction (Contd.)

Well so good morning to all of you. So, today we will be continuing our discussions on the estimation of void fraction as well as the frictional pressure gradient. So, in the last class what we did was we discussed that primarily these your the approach to find out the frictional pressure gradient in accesses any for the information it is primarily empirically in nature. And the empirical correlation they are mainly they are expressed in terms of 2 phase multipliers, which express the 2 phase pressure gradient in terms of known single phase pressure gradient quantities. They can be single phase pressure gradient when the liquid flows alone in the pipe, single phase pressure gradient when the gas flows alone in the pipe or single phase pressure gradient when the entire mixture flows as a liquid or as gas in the pipe.

So, these are the these are the four ways in which rather four 2 phase multipliers with the help of which 2 phase frictional pressure gradient can be expressed in terms of equivalent single phase pressure gradient terms. The other thing which I discussed is instead of phi lo square and 5 g phi lo square and 5 g square please remember they are very use full for boiling condensation situations square may be in the liquid it entries at so saturated slightly lower than saturated conditions inside the pipe, and they change of phase as it goes on. After this, what we discuss for that pipe in the separated flow model we prefer to use 5 l square and 5 g square instead of phi lo square and 5 g o square.

We found that day confirm to certain limiting conditions and that is why we prefer that after that what we did, we found out the graphical as well as the analytical correlation between phi l square and 5 g square, the oldest and the most widely used correlation which has been proposed by Lockhart and Martinelli. So, the graphical correlation has been expressed in terms of the graph which I have shown in my transparence, this particular graph it shows the graphical correlation between 1 by phi l square and 1 by 5 g square.

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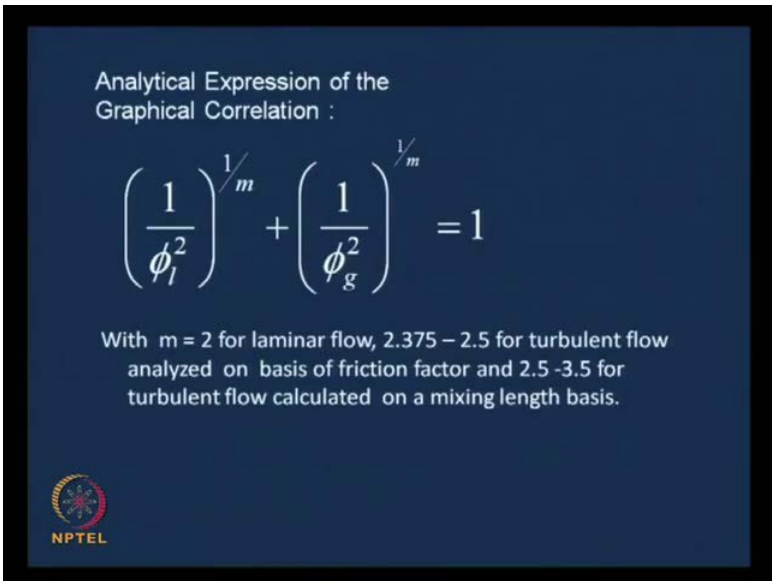

And then subsequently we derive the analytical expression, where the analytical expression it is of this particular form, and we find that the analytical expression takes of different forms or takes up different types provide depending up on whether the flow in the 2 phases laminar or turbulent, and also for turbulent flow whether the we use Blotious type of equation or whether we whether the turbulent flow is calculated on a mixing link basis.

So, this mixing link basis was your homo assignment yesterday. The other thing which so after this the next thing which I was trying to do yesterday I could not complete it, so I will be doing that portion and then we will be go going to further discussion regarding the improvements of this particular correlation. Now the problems of this correlation as you can very well see that both phi l square and 5 g square they contain the 2 phase pressure gradient term, is not it, this is the known this is the thing which you want to find out therefore, in the annually your graphical expression.

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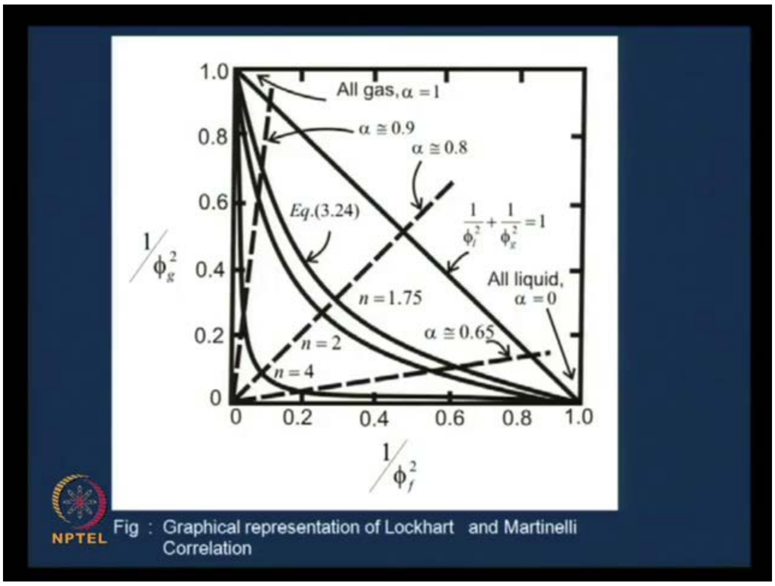

If both the x and y access they contained the unknown parameters, so actually from here if you want to find out the 2 phase pressure gradient term then you have to use a try line array technique. Is it not? Because the both the x and y access have got the unknown pressure gradient term.

So therefore, in order to avoid this what are the different things we use, what are the other correlation those things will be discussing in the present class, but before we go to that the things which I had told you in the last class was the correlation was based on certain assumptions, if you remember the assumptions.

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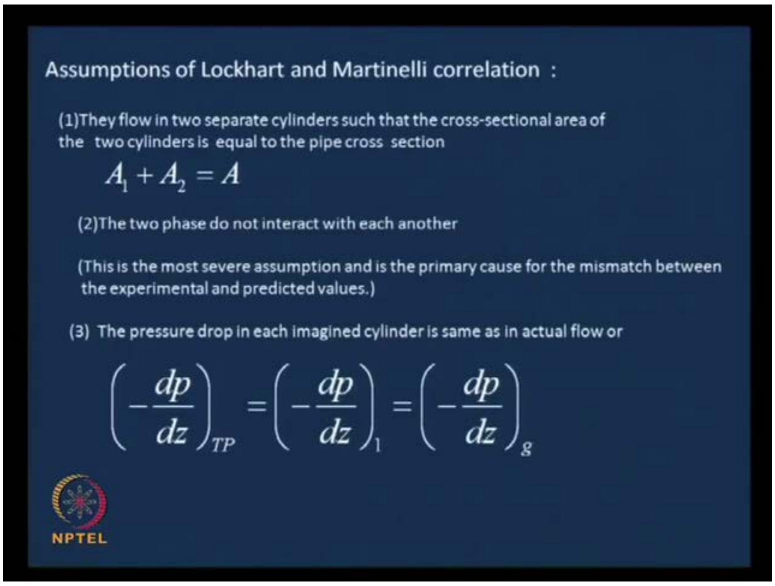

We have already discussed in the last class the assumption the first one is fine, the only thing is that we assume that both of them flow in 2 separate cylinders, such that the cross section area of the 2 cylinders equal to the pipe cross section, remember one thing even for stratified flow, if we can assume that well they are more or less cylindrical, but definitely in annular flow we cannot assume it. The liquid film cannot be assume to flow in a cylinder.

So, naturally if you have to take an equivalent cylinder for the for the annular for flow case then the shape factors as to be accounted for is not it. So, this is the assumption the other this the animally in the in the assumption one which have stated here, the next assumption was the 2 phases do not interact with each other this was a very serious assumption and that we will see shortly, in fact at started in the last class I had try to apply the separated flow model after deriving the analytical expression, what I try to do is I try to find out phi l square for annular flow by considering the actual flows circumstances and by considering the Lockhart Martinelli correlation, and I wanted to show you how well these two particular expressions they agree. I could not completed today I will be completing it.

So, I would like to show you that there are some discrepancy in the separated flow model it does not give us exactly the same results which we would get if we considered the actual flow characteristics and will be showing it using the annular flow up flow situation which indeed separated flow situation, but in this particular separated flow situation certain assumption they do not hold. Well the other assumption the follow as results of these assumptions so will not be going into the details of this, now to continue with a discussion with the annular flow situation which we had use and other which at started in the last class. So, I would just recollect what I had discussed in the last class before I proceed for further. The first thing which we had cough there was I had obtained and the thing which I did was in the last class I had first show discussed that how to when we want empirical or sorry a graphical are an analytical expression for phi l square and 5 g square.

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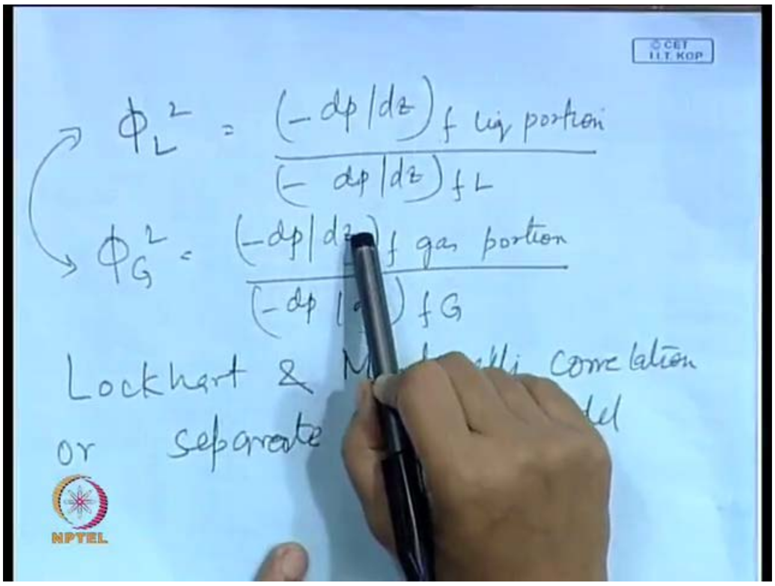

So, how to define these two, phi l square suppose you take this is the frictional pressure gradient in the 2 phase condition. As ratio of the frictional pressure gradient when the liquid content of that particular mixture flows alone in the pipe, based on the assumption of Lockhart and Martinelli correlation.

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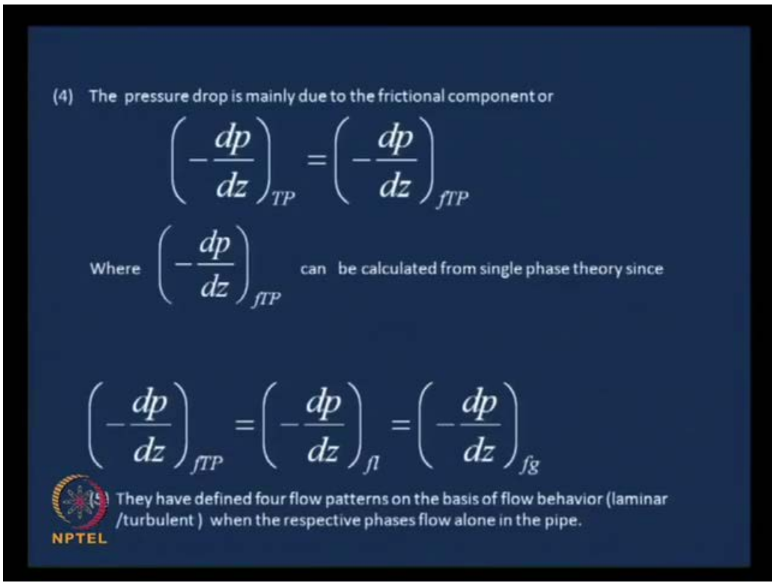

If you see assumption 3 which have written down in the transparency, assumption 3 and assumption 4 which gives you this particular expression? So, based on this expression the thing which had written down in the last class was phi l square was minus d p d z frictional for the liquid portion of the flow divided by the frictional pressure gradient. When that particular liquid flows alone in the pipe, so based on this we have derived the frictional pressure gradient for the liquid portion,

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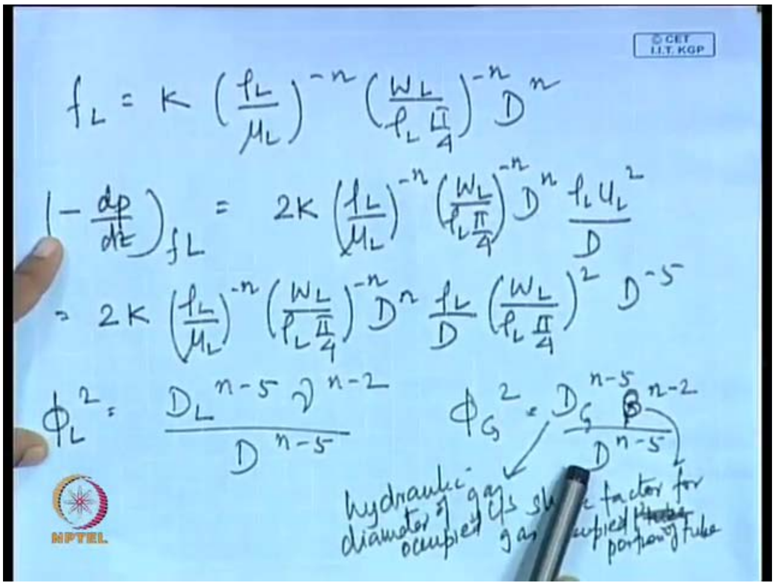

and then we have derived the fictional pressure gradient and that liquid flows alone in the pipe, and finally, from those expression I had obtained 5 expression for phi l square and I had set that is similar expression exits for 5 g square as well. Now if he considered this particular phi l square here what do we get.

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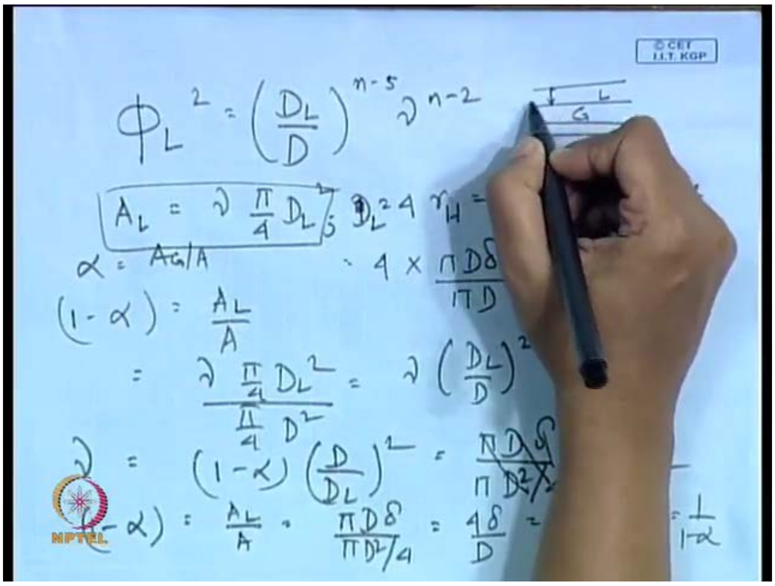

By considering this particular phi l square this was D L by D whole to the power n minus 5 gamma whole to the power n minus 2. Now, in this particular case what is DL what is AL the cross sectional area of the liquid occupied portion of the pipe, it is naturally gamma 5 by 4 DL square, agreed this the D L it is the hydraulic diameter it is nothing but 4 r h for r h is the hydraulic radios which is nothing but 4 in to you remember it very well it is wetted area divided by the wetted perimeter is not. So, therefore, what is the wetted area in the in the annular flow case? Suppose you take up the annular flow case I have already drawn it in the last class, this is the gas code; this is the liquid fill; so what is the wetted area in this particular case, and what is wetted perimeter in this particular case,

And very sorry sorry DL equal to when I wanted to say the DL equal to 4 r h any how sorry, so I just wrote it yeah it is all now.

So, what is the wetted perimeter in this particular case?

What is it?

Phi D delta and wetted perimeter equal to phi D. So therefore, you 4 r h equal to 4 delta agreed. Well so in this particular case this DL it can be substitute by 4 delta fine. Now what about this gamma, how to substitute gamma, now we know one thing what is one minus alpha equals to alpha equal to A g y a agreed, 1 minus alpha it should be A 1 by a agree, what is A L have already written it down it is gamma phi by 4 D L square by phi 4 D square fine, in other words this is gamma DL by whole square agreed. So, what gamma the shape factor this is equal to 1 minus alpha D by DL whole square fine. Or in other words this can be written down as what is your so this; and therefore, this is equal to 1 minus alpha D by DL whole square agreed.

And now what is this 1 minus alpha equal to it is nothing but DL by d whole square and what is DL 4 delta? Is it clear to you, see what is 1 minus alpha AL by A agreed, what is this AL by a this is nothing but can you write it down just see for time doing phi D delta by phi D square by 4, can you do it yes or no?

We can do it is not it, try to understand you can express it either in terms of DL or in terms of d and liquid fill thickness delta is not it. DL is the hydraulic diameter of the liquid film, if you have to express it terms of DL than the as to be shape factor, or in other words you, but this particular thing is based on the assumption that a liquid film thickness is much less as compare to the two dimensions. And it the things the assumption which I told you in the last class I do know whether I have that particular slider not that the interface is completely smooth, it is much thin as compare to the two dimensions.

Under that conditions from flat plate assumption we can take d as your sorry yeah from that particular situation we can write L minus alpha this is equal to AL by a which is nothing but gamma phi by 4 DL square by phi by 4 DL square, or this can also be written down as phi d delta by phi d square by 4, sorry so I should not have written it down here is not it. Can I dick can I write this agreed, if the liquid film thickness is much less as compare to two dimensions definitely 1 by alpha can be express in this particular form yes or no, yes for what is this basically this is 4 delta by d, yes or no agreed, and which is nothing but equal to DL by d is not it. So therefore, what is d by DL equal to from here for do we get d by DL is nothing but 1 by 1 minus alpha agreed. So therefore, what is gamma than equal to? This gamma than this is equal to 1 minus alpha and d by DL whole square means 1 minus alpha whole square. If you want me to repeat I am going to repeat it once more, is this portion clear to you.

So therefore, I have got gamma I have gone depressional DL by d, both of them I have got in terms of alpha delta etcetera, alpha is a word fraction, delta is the liquid film thickness this is the delta portion, and the word traction is alpha.

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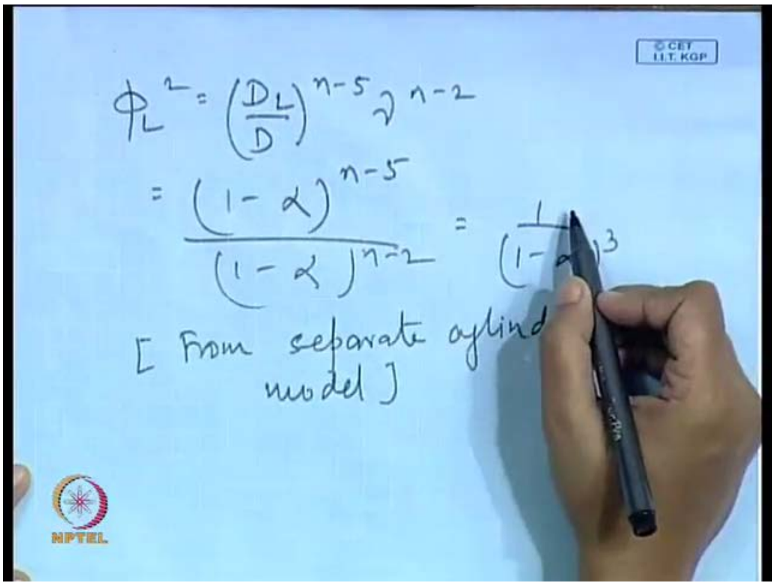

So therefore, from here for do I get then from here I get this phi l square and write it down once more this is DL by d whole to the power n minus phi gamma to the power n minus 2. What is DL by D? It is nothing but 1 minus alpha whole to the power n minus phi, yes or no fine, and what is gamma? This is nothing but 1 by 1 minus alpha, so therefore, this will become by 1 minus alpha whole to the part n minus 2 fine. So therefore, this is nothing but equal to 1 by 1 minus alpha whole cube agreed, this we have obtain from separate cylinder model.

So, from separate cylinder model based on the assumption what was the assumptions it was based, that the two flows its flowing separate cylinder where the cross section area of the cylinders adopt to give us the cross section area of the pipe. Number one do to fit what could you say we could express A 1 in this particular form.

And A n this particular form number one, what was the next assumption that we assume we assume that this phi l square it can be defined in terms of the frictional pressure gradient in the liquid portion divided by the frictional pressure gradient, when that liquid flows alone in the pipe. And how did I take up the frictional pressure gradient in the liquid portion to b equal to the frictional pressure gradient in the 2 phase mixture, because I have assume that the 2 phase s do not interactive with one another. So, based on these assumption what did we get we obtain phi l square as 1 by 1 minus alpha whole cube from the separate cylinder model. Now let us see what we will be obtaining if we considered the homogeneous flow situation, now considering the homogeneous flows situation, yesterday I had already started the derivation for the homogeneous flow situation and all the started the derivation yeah.

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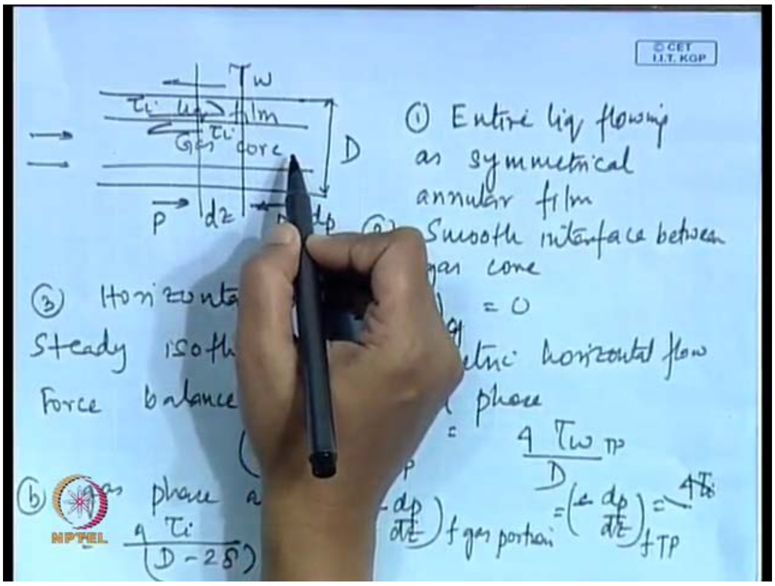

So, in the last class I have already started the def the derivation of the homogeneous flow situation, where I have written down the assumption that quite justified I should say, entire liquid flow flowing as a symmetrical annular fill, and there is smooth interface between film. And gas code add these assumption not been applicable we could not have written AL as phi d delta is not it, and they off course it is a horizontal pipe.

So, where gravitational pressure gradient is not there, so from this particular case what we did we performed a 4 balance on the combined phase and we obtain this particular expression. It was just the wall shear stress we try to related with the frictional pressure grade sorry we try to related with the pressure gradient were the pressure gradient here is spread dominantly frictional in nature. It is A 1 water case that we have considered for this no change of phase no gravitation pressure gradient nothing for that matter. Than for what we did we try to perform the force balance on the gas phase gas portions alone, from the gas portions alone, if we just considered then in that case we obtain the instead of this expression you obtain this expression where d minus 2 delta is the effective diameter of the gas code, it can be taken as D G if that matter is not it. So, accordingly we have written down the gas phase or other we have we have obtain the expression for minus d p d z f the gas portion in this in this particular case.

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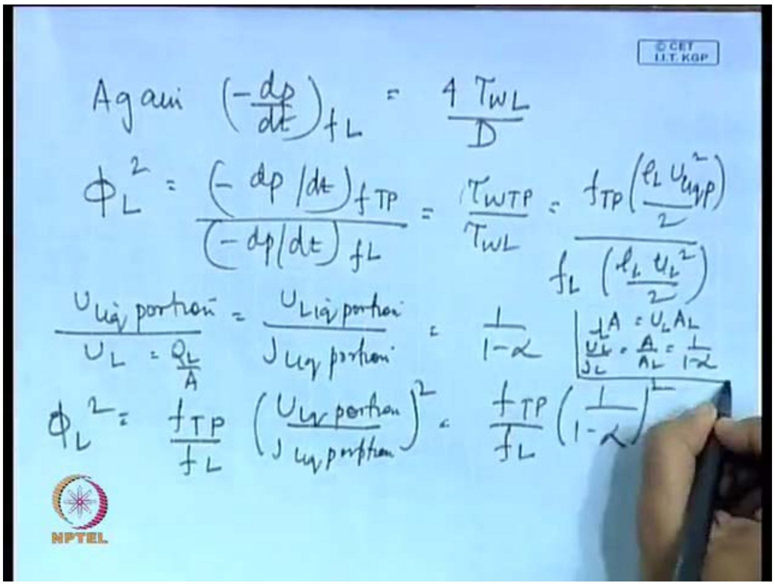

Now, remember 1 thing after that what we did, suppose we would assume see we want to find out phi L square. So, what is phi L square? phi L square is nothing but n 2 phase frictional pressure gradient divided by pressure gradient when only liquid flows in the pipe, so for finding out phi L square we have to find out the pressure gradient and only this liquid flows in the pipe. And what is the pressure gradient when the 2 phase mixtures flows in the pipe that can be taken to be equal to that press frictional pressure gradient when in the gas code or in the liquid film.

So, in this particular case we are taken it to be in the gas portion agreed, well anything if you do not if you do not understand just tell me to repeat that particular part, so after that once we have found out minus d p d z f TP, sp after that the next thing was to find out minus d p d z when frictional pressure gradient when the liquid portion the liquid film flows alone in the pipe. That was nothing but this is not it, and then phi l square it could be expressed as tau w TP by tau w l yes or no.

Fine now what is this tau w TP it is in terms of frictional pressure gradient we can write it down in the this particular path, where we find that the wall shear stress for the 2 phase situation that depends on the velocity of the liquid portion. At in this case it depends up on the velocity if in that liquid is flowing alone in the pipe, or in other words if that liquid as to flow alone in the pipe then the velocity.

If which it would have is nothing but the volumetric flux or the superficial velocity which is nothing but q l by A agreed, so therefore we find that u liquid portion by u l this is nothing but u liquid portion by j liquid portion yes or no. And then for do now we now j the volumetric flux into area is nothing but u l by A 1 do we know this or in other words your u l by j l this is nothing but a by A 1 yes, and what is this A by AL? This is nothing but 1 by 1 minus alpha. Everything if see it is you may if you notice one thing whatever we I am trying to derived everything is already available your already studied in single phase hydro dynamics.

And certain very basic definition which we have done, all the derivation are base and just these two things, if you have single phase hydro dynamics concepts are clear, if you remember the new nomenclatures which we have defined that to the very basic nomenclatures, like void fraction. And mass quality, then probably all the derivations you can make, the only thing which you have to keep in mind is that you should not make mistakes and to should not confuse between what you doing, whether your finding out the pressure gradient when liquid flows alone in the pipe.

Whether you finding the pressure gradient when that liquid flows as a film as separate layer 2 phase flow, you have to keep this things in mind accordingly you have defined the velocity accordingly you have defined the diameter, these things are done properly then will have no problems with 2 phase front, you will not thing that there are too many nomenclatures too many derivation and the calculation are long. They are long just because the involves more number of properties or more number of parameters as compare to single phase flows, but the concepts are essentially the same.

So, if you see finding out your frictional pressure gradient or the wall shear stress, the expression which your you the you already know them from a single phase equations, nothing new I am doing, but you have to keeping mind exactly what your trying to do and you consistent things, if your finding out the velocity of liquid portion keep in mind that this velocity will be equal to the q liquid divided by AL. If that liquid flows alone in the pipe it will be equal to QL by total cross section area, so these small things you have to remember. So therefore, from here for did we get we found out that u liquid portion by u l was nothing but 1 by 1 minus alpha fine.

Now, if you want to find out phi l square for the actual annular flow situation, then in that case it is nothing but f TP by f l into u liquid portion by j liquid portion agreed, f TP by f l into 1 by 1 minus alpha whole Square till this portion do you have any doubts you tell me yeah.

(( ))

Annular strictly annular, why did you thing it is homogenous were this homogeneous think can you tell me?

(( ))

Louder.

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No I did not mention homogenous at all, it was exclusive I first mention this separated flow model. The Lockhart Martinelli correlation, so things which I did was this is what I want you show you is how accurate the Lockhart Martinelli or the separate cylinder model is…

So far that I took up real it truly separated flow situation, what situation did I take annular flow situation in horizontal pipe, where there is no face change uniform the diameter of the horizontal pipe and it is by it comprises of very narrow liquid film and the interfaces smooth, and idealized annular flow situation where the entire liquid flows as film and entire gas flows as the code agreed. For this particular situation I applied the Lockhart Martinelli correlation in this particular case, and I tried to find out phi l square from the Lockhart Martinelli correlation, what did I get I obtain phi l square is equal to 1 by 1 minus alpha whole cube fine.

Now, I would I wanted to take up the actual flow situation and try to find out phi l square from here fine. So, for finding out phi L square what do I need? I need the frictional pressure gradient in the liquid portion, or in the gas portion, or in the 2 phase mixture divided by the frictional pressure gradient, when that particular liquid flows alone in the pipe agreed. So therefore, what did I get I obtain from this entire derivation phi l square to b f TP into f l into 1 by 1 minus alpha whole square, this has nothing to do with homogenous mind it. It is simply a separated flow model first I tried to find out phi l square using the separate cylinder model as proposed by lock hart and Martinelli, then I try to find out phi l square from the actual flow situation agreed.

So therefore, what did I get in this particular case it is f TP by f l into 1 by 1 minus alpha whole square agreed. Now in this case we trite to observe something, now this f TP or in other words if we start from us slightly all other here also this f TP are this tau w t TP it arises why, because the liquid film is in contact with the wall agreed.

So therefore, this mast; or this must depend and fort any fiction factor depends on Reynolds number. So therefore, this will depend upon the Reynolds number of what of the liquid fill, it will depend up on the Reynolds number of the liquid film yes or no. And this f l will be depend upon that liquid flow in alone in the pipe, what is the difference between Reynolds numbers when liquid flows as film and when liquid flows in the whole pipe? Basically the velocities will be different, the hydraulic diameters or going to be different agreed. So therefore, this f TP this is function of your film Reynolds numbers, and what is this film Reynolds numbers? This is just it is 4 delta which is nothing but DL u fill row liquid by mu liquid do you agree with me? Do you agree with me?

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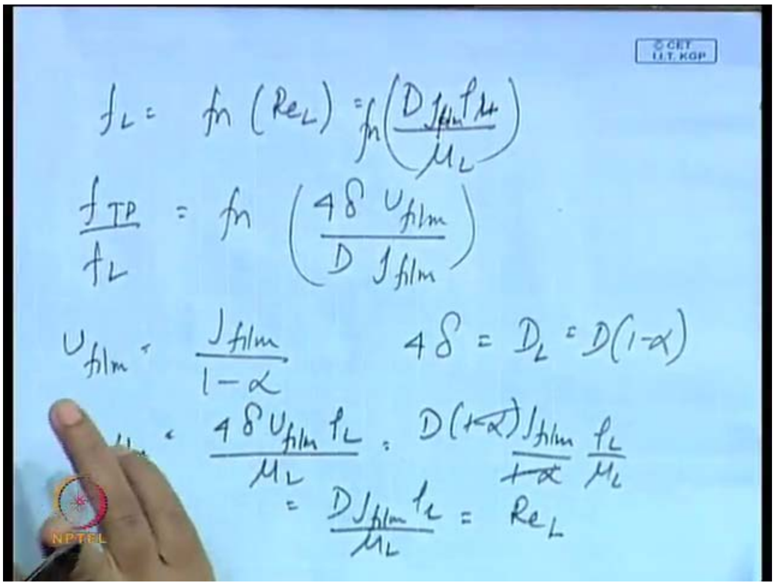

And what is this f L equal to f L it is function of r e l, so this is equal to d if I take it as j l row sorry row l by mu L yes or no. Now in this particular case what do I get, so therefore, I now f TP by f L this will be function of just a function of I will not write the details 4 delta u film by d j film j f r j film whatever you write down yes or no do you agree with me. Now we know what we know u film equal to j film by 1 minus alpha do we know this fine?

We know this and next what l s to we know, we know from there 4 delta was equal to D L that we have just derived which is nothing but equal to d into 1 minus alpha is not it, just in fact I think 1 or 2 slides back only I had derived this particular situation, here I had derived it, that yeah 1 minus alpha equal to 4 delta some where I have derived it find it now, here only I have derived DL equal to 4 delta, just no I derived it.

So therefore, so from these two things what do we find? We find that than Re film this is equal to 4 delta u film row l y mu l so instead of this 4 delta I can write d into 1 minus alpha. And instead of this u film I can write j film by 1 minus alpha row l by mu l, can I write this yes or no? Can I write 4 delta is D into 1 minus alpha u film us j film by 1 minus alpha? No problem, so therefore what does this we reduce to d j film row l by mu l is not it, which is nothing but equal to r e your liquid fen only liquid flows to the r e l and the entire liquid flows in the pipe whose compare this expression and this expression agreed. So therefore, from this for do I get? I get the f TP equals to f l for this special situation of annular flow horizontal pipes liquid film very thin smooth interface.

For this particular consideration what do I get? I find out that the Reynolds number for the liquid film interestingly is equal to the Reynolds numbers when that particular liquid flows alone in the pipe. As result of which I can express your f TP equal to f L fine. And therefore, what is phi l square than from this particular for this annular flow case? It is 1 by 1 minus alpha whole square, do you get my point, so therefore, for from this what did I get I obtained phi l square as 1 by 1 minus alpha whole cube, but in reality by considering the annular flow situation in reality from the annular flow situation we obtain phi l square equal to 1 by 1 minus alpha whole square. So, this particular contradiction this tells us why rather were these two cases, it will not tally. And the this particular discrepancy this primarily occurs, because we have not considered the interaction between the 2 phase.

Yes, since we have not considered interaction what was the basic thing that he could take, the frictional pressure gradient in the gas code is equal to the frictional pressure gradient in the total 2 phase mixture, this was the first thing that we had considered. If you see here, so therefore, the primarily the main reason for this particular discrepancy it arose because we neglected the interaction between the 2 phases.

So therefore, the what I want to emphasizes is that this is not fuel proof correlation, but this has been tested extensively with the large number of data, this was proposed in the 1944 to 45 that particular regime, from then on more or less lot of modification of this particular correlation as been propose, but more or less some sort of form has be maintained, and the main reasons for this is that it is a extensively used and within reasonable limit it gives us proper estimate of the frictional pressure gradient, but when you are using this remember that there are certain assumption out of which thus most seviour assumption is that the 2 phase s do not interactive with one another, because that implies that 1 phase is not aware of the presence of the other case.

So, in that case its almost similar to say that two single phase flow situation are occurring, but the basic definition of 2 phase flow is interacting flow of 2 phases. So, there the problem rise but otherwise more or less we can use this, so this was thing which I wanted to show you, now will come back to Lockhart and Martinelli expression and we will try to see for other modification has been proposed and accordingly will be proceeding. Now the first thing if you notice for this Lockhart and Martinelli correlation we find that phi that this gives us correlation between phi L square and phi G square.

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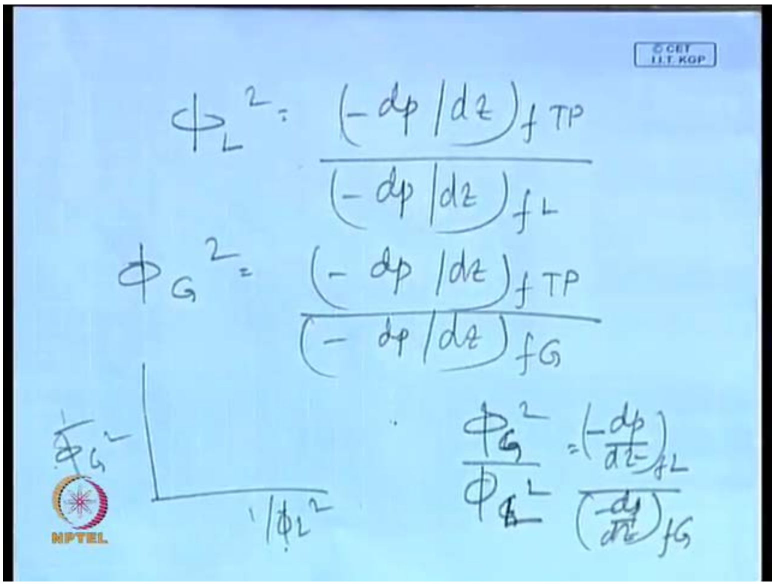

What if you remember the basic definitions, I do not know whether I have the definitions here, I do not think I had done here, the basic definitions I will just write it down once more, the basic definition was phi l square was minus dp dz frictional 2 phase by minus dp dz frictional when that liquid portion flows alone in the pipe phi g square was minus dp dz frictional 2 phase divided by minus dp dz frictional from the gas place flows alone in the pipe, I try to derived a correlation between 1 by phi G square and 1 by phi l square. So therefore, I why I want to do this just to find out the frictional pressure gradient, now we find that both in the y axis as well as in the x axis we have this particular unknown, so therefore, if you have to find out frictional pressure gradient from this particular correlation beet analytical beet graphical than it has to involve try line array technique is it not? There is unknown both in the x as well as and y axis.

So, just to eliminate that particular problem what researches afraid to do, they have defined rather they have divided phi l square by phi g square, once you divide this what happens this is simply ratio of what you tell me this is this (( )) sorry it is phi G square by phi L square. So, this basically becomes ratio of minus d p d z frictional, when the liquid flows alone in the pipe and this is minus dp dz frictional, and gas flows alone in the pipe so this becomes a known quantity, now its phi L square and phi G square is plotted as a function of this particular ratio, then if this is the x axis then we know the x axis already, we can calculated once we know this then we can go to calculate phi l square and phi g square whatever is there in the y axis is not it.

And we can find out frictional pressure gradient in the much more simpler fashion, so this ratio it is denoted as capital X square please remember do not write it a small x, because small x gives to mass quality and this is a Lockhart Martinelli parameter as it is said. This is the capital X, make it in very bold capital so that your self do not confuse it with quality, remember this.

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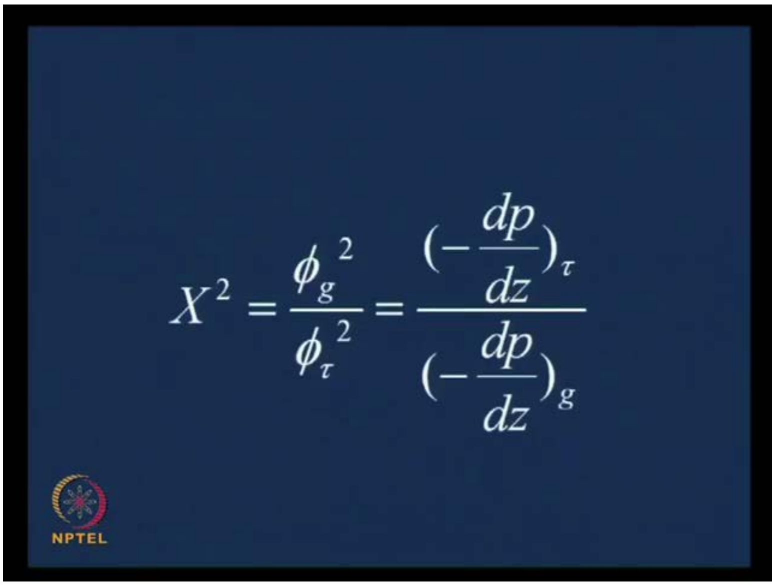

So, the next attempt which was done was to plot your phi L square phi Gsquare, either it is phi L square or it can be phi g square as a function of x square, so therefore what we have with e, we can find out x square moment we can find out x square, because of their we can find out phi L square moment. We can phi L square we no dp dz f l, so we can find out the fictional the 2 phase frictional pressure gradient clear to all of you.

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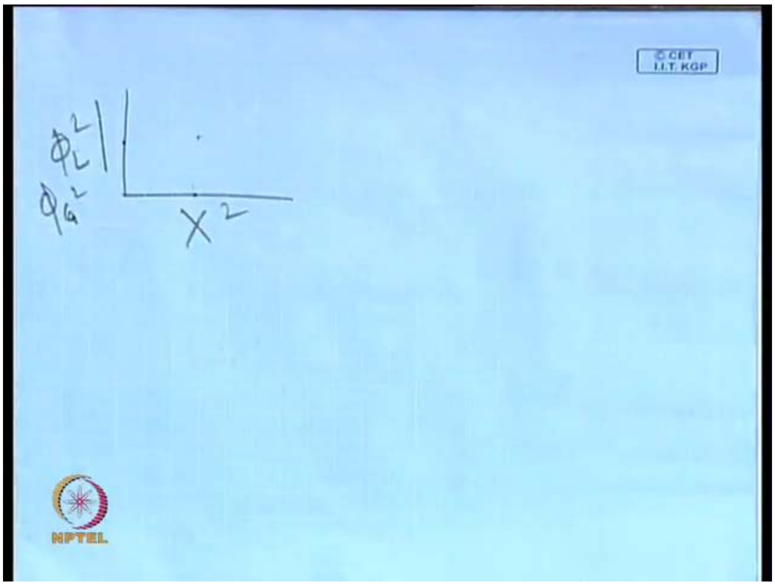

So therefore, the next attempt you are made to correlate not phi l square and phi g square, but to correlate phi l square or phi g square with x square for a x square is known as the Lockhart Martinelli parameter agreed. So therefore, the graphical correlation I already have this is the graphical correlation.

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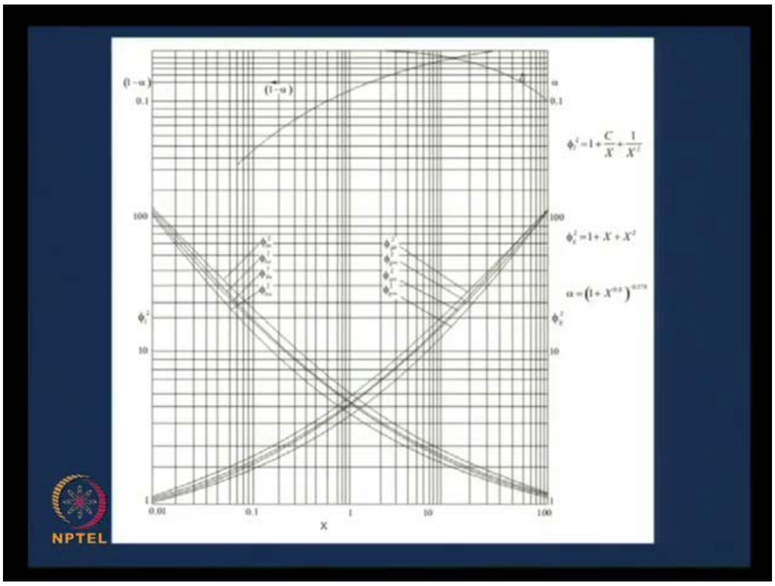

If you see this correlates phi L square this should be x square actually, this correlates phi L square with x square these are the graphs here, remember here its notice properly, we have 4 sets of cause phi, because one considered I think they vary the writings are very small, any how I will just mention them, one considered both phases in laminar flow, other considered both phases in turbulent flow. And in between the considered one phase is a laminar and other phase is in turbulent.

So, depending up on the 4 situation we have 4 different curves these are for phi l square and these are phi g square. So, these are the different graphical curves. Now, your situation becomes much more simpler, you know x square you can find it out x square, you know whether the liquid and the gas at flowing in laminar or turbulent flow, accordingly you select one particular curves from this family of curves. And then from there you come to the y axis you find out phi L square or phi G square, which very your required to find out from there you find out the frictional pressure gradient. So, this is the actual situation which is usually used or which is usually done in this particular case. So, in this particular case what is this X square? This X square it this is slightly wrongly written this should be liquid, it has been wrongly written as tau but it is actually l.

So therefore, this x square by definition it gives measure of degree to which the 2 phase mixture behaves as the gas rather sorry behaves as the liquid other than the gas, it is basically the frictional pressure gradient ratio of frictional pressure gradient between that of the liquid and the gas, or it rather it gives you the degree to which the two phase mixture behaves as a liquid other than the gas. So, this is basic definition, now remember and this particular correlation which I have shown you this particular correlation it has been verified with a large number of experimental data.

And then it was also felt that if the frictional pressure gradient can be correlated with x they should also exists a relationship between void fraction and X as well, so the void fraction was next plotted as a function of X, I have show in many text book will find that the difference sets of curves for phi L square. In fact, values it will see we will find that they have given 4 sets of curves, for both phases inter laminar both phases in turbulent and so on and so forth.

But here have condensed everything, so that it is easier from one particular graph you can get all the information. So, here you find that if we plot alpha words is a X square or L minus alpha words is x square in this particular graph that I have drawn. You find that in this particular case interestingly for all the 4 cases, if you see this the transferring the presentation which have prepared here, in this particular presentation if you see we find that phi L, in phi L square verse X you have 4 separate curves for laminar Laminar, turbulent turbulent, laminar turbulent this particular cases here we have 1 particular graph.

This is the graph of 1 minus alpha and this is graph for alpha verses X square, so in this particular case we find that this the relationship between alpha, and x square this is independent of flow patterns, independent of the way the 2 phase s flows in the alone in the pipe.

And this particular expression which I have drawn here, this can be mathematically represented by the analytical expression which have shown here, I do not know whether it is evident or not, so I will be writing down the analytical expression, it is alpha equals to 1 plus x to the power 0.8 whole to power minus 0.378, so therefore this is this was the analytical expression. Now remember certain things this the things are out of these particulars 4 curves that I have shown here, in this case it is very rare that the gas flowing alone will be turbulent and the liquid flowing alone will be laminar. So therefore, this case is not but much use, but these particular curves can be use and we find that the curve gives you a comprehensive idea about how phi L square and alpha vary with X square.

So, from this one curve if u can calculate X square, you can phi L square, you can calculate alpha, moment you can calculate both this equations or both this particular quantities, we can go to the mixture moment equation which we have derived for 2 phase separated flow, they were only 2 unknown there if you remember if you see that expression one was the friction pressure gradient at the another was the alpha. If we can calculate alpha we can calculate the gravitational pressure gradient, if we can calculate your frictional pressure gradient, then from these to quantities, we can calculate each and every individual terms which will there in the mixture momentum equation which was used for calculating the pressure gradient in 2 phase s are flowing under separated flow conditions.

Now, just remember certain things the things are that this particular correlation which I have shown you this is used specifically for horizontal flow without phase change. So therefore, it is more preferable for air water for sting water flows, it has not been deriver it has not been derived for that particular situation. So, the correlation was specifically dev derived for horizontal flow without phase change or significant acceleration, and it can be used to calculate both the void fraction and the pre frictional pressure drop, even when these effect and not negligible also it can be used, when we have some amount acceleration pressure drop they under that circumstance also it can be used.

But remember one thing the more important the other components of pressure drop become the less important frictional component of the pressure drop becomes, the more inaccurate the correlation becomes, because the basic thing was based on the fact that the 2 phase pressure drop primarily comprised of the frictional gradient. So, moment that is violated, we the resulting error becomes more, but very frequently for people do they find out the frictional pressure gradient from here and accordingly the they calculate the gravitation acceleration, and they can calculated the total pressure gradient. That is also done for this particular case, and we find that the correlation which as shown you graphical here this is Essen it balance the frictional shear stress verses the pressure drop, this particular graph.

But the only thing which we as to remember in these particular cases that more or less number of workers have also fine found out. That 2 phase frictional multipliers this phi L square and phi G square, they can be correlated uniquely as parameter as function of this particular parameter X, were X was defined in the way that I have already mention, this keeps to measure of the degree to which of the 2 phase mixture behaves as a liquid rather than as gas. Now subsequently a large number of other modification for suggested. What was the first modification? First modification was an analytical expression can be proposed which would condense this curve into equation that would be very useful.

And subsequently people have to tried to find out the analytical expression, and I have written down the analytical expression on the side of the graphs civics it is visible to you I do not know, it is phi L square equal to one plus c by x plus 1 by x square, and phi G square equals to L plus x plus x square.

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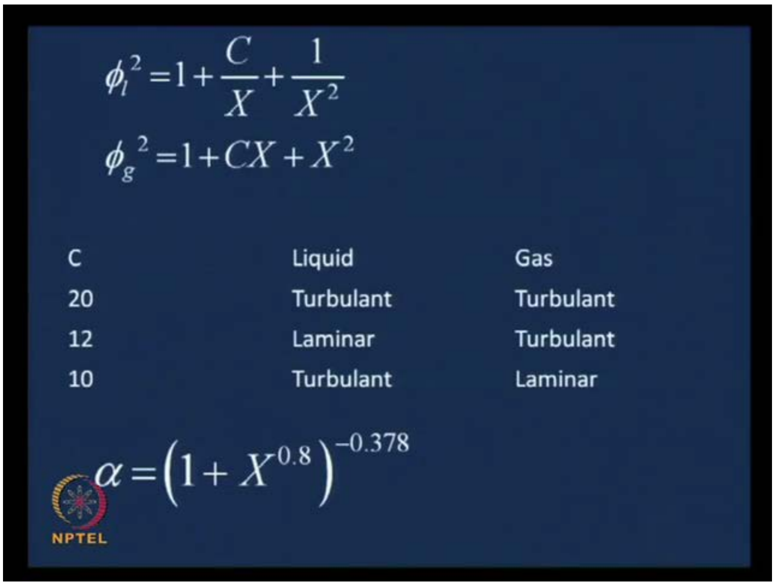

Where the value of C takes on different values for these are the corrected expression, this was sorry this should have been C X, so these are the corrected expression if you want you can take the down, where we find the value of C is different for different types of flow of liquid and gas when the flow alone in the pipe. In fact, the turbulent spelling is also wrong here, so those things since your master as fluid mechanics you are doing multi phase flow advance flow dynamic this should not be a problem for you. So, we find that value of C is 20 when both liquid and gas are turbulent, the value of C is 12 and liquid laminar gas turbulent C is 10, and liquid turbulent gas is laminar and so and so forth it goes on in this particular case.

And one more as been missed out C is phi you can note it down, C is phi when both liquid and gas are laminar, that has been missed out here you can just note it down. Remember one more thing also that these particular correlation have been derived for 2 phase 2 component system at in horizontal flow at low pressure close to atmosphere equation is not it. They have been derived under that condition also, so it is application to situations out sides this range of consideration is not recommended.

So, remember this part also. So, therefore it able these things have to be considered in the next class we will be dealing with certain generalized, certain modification, certain improvement of this particular correlation, and that will finish of our separated flow model. Thank you very much.