Adiabatic Two – Phase Flow and Flow Boiling in Microchannel

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Lecture – 24
Tutorial I

Good morning everybody, myself Ritwik Maiti, research scholar From department of mechanical engineering, IIT, Kharagpur. So, this is a tutorial class on adiabatic two phase flow and flow boiling in Microchannel. This class has a 2 section, in the first section Mr. Alex Koshy will discuss some numerical problems related 2 phase flow and it is based on the classes, which have been conducted and this is a part of assessment of this course.

So, he will discussed one problem related to nomenclature type and 1 problem related to calculation of pressure drop, in a typical 2 phase flow, when it flow through a conduit and in the second section mainly, content with the computation of fluid dynamics in 2 phase flow and this is a not part of this assessment of this course. In this part Mr. Vinmay Dhor will discuss in C F D and C F D in 2 phase flow. He will also discuss in briefly, the stimulation of 2 phase flow with the help of open source like jets and then Mr. Abhir Chakravarthi will also discuss simulation of 2 phase flow to find out the flow pattern and pressure drop with the help of commercially used software package like console. Now I am just hand over this class to Mr. Alex Koshy, Thank you.

Hello everyone, I am Alex Koshy. I am the T F for the course adiabatic 2 phase flow and flow boiling in Microchannel. So, in this tutorial, I am going to explain few a numerical problems that are related to multiphase flow. So, the first problem as Mr. Ritwik Maiti has already given introduction about what my session will be, the first problem is a nomenclature related problem and the second 1 is a typical multiphase flow problem, that deals with the pressure drop calculation, that is involved when a 2 phase mixture flow through a micro channel.

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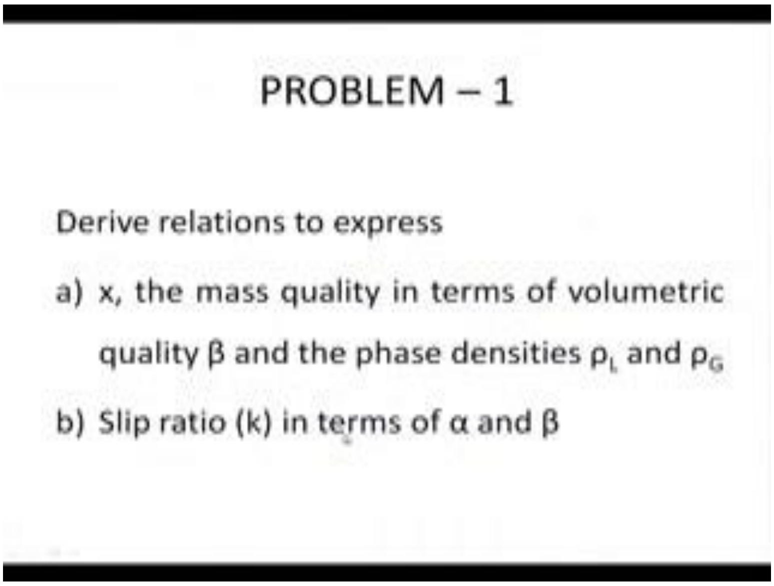

So, I am going straight to first problem. So, I will read it once. Derive the relations to express x the mass quality in terms of volumetric quality Beta.

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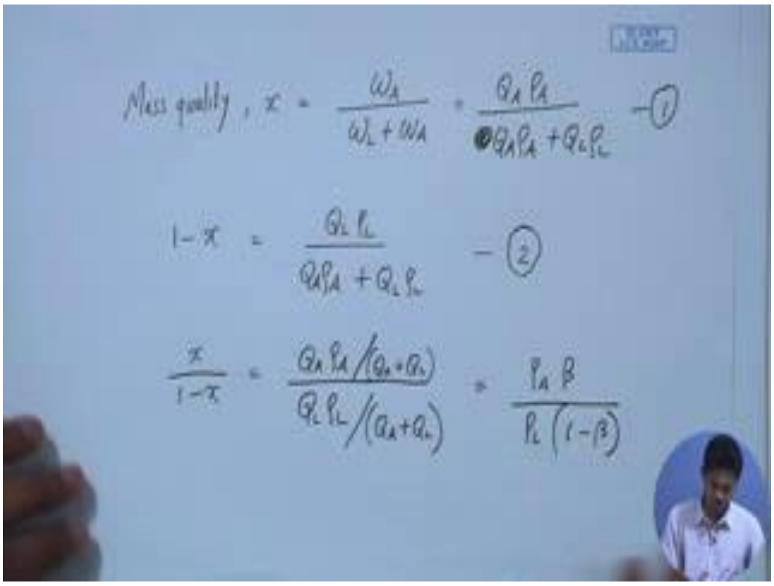

And phase densities Rho L and Rho G. Mass quality of air in the system suppose, it is an air water system, the mass quality air in the system can be represented as W A by W L plus W A where A is the W A is the mass flow rate of air and W L is the mass flow rate of liquid and it can be written as QA rho A by QA rho A plus QL rho L, where QA and QL are the monometric chlorides of air and liquid phase and rho A and rho L are the phase densities; in the similar way we can write one minus x that is a mass quality of liquid phase as Q L Rho L by Q A Rho A plus Q L Rho L. Alright, here Now this is equation 1 and this is equation 2. So, we are dividing 1 by 2 therefore, we will get any equation like X by 1 minus X is equal to Q A Rho A by Q L Rho L.

Now , I am dividing both the numerator and denominator of this equation of this term with Q A plus Q L. Now if you see, we are having Q A divided by Q A plus Q L term here in the numerator and Q L by Q A plus Q L term, here in the denominator and this is nothing other than Beta, that is volumetric as a volumetric ratio volumetric flow ratio at the inlet and here Q L by Q A plus Q L is 1 minus Beta.

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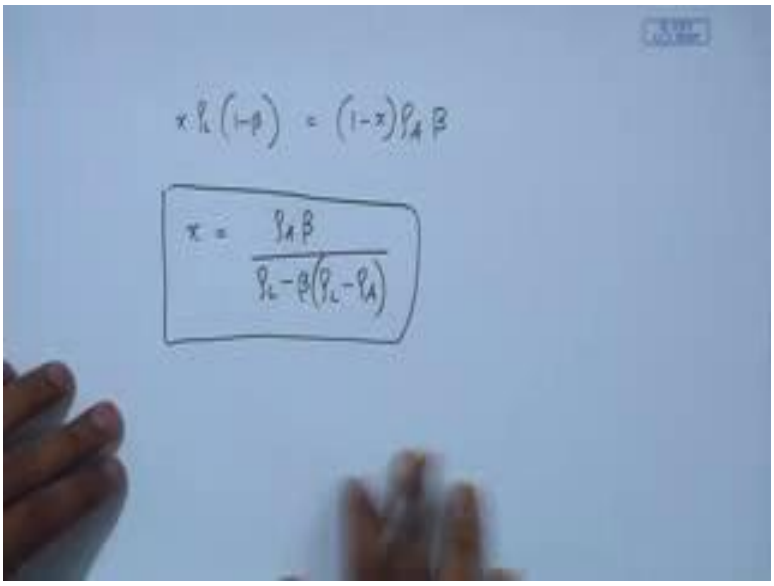

Now , I am simplifying that equation by cross multiplication, Now after further simplification. We will get the value of X as, we can express X as, Thus we have expressed X the mass quality in terms of Beta and phase densities.

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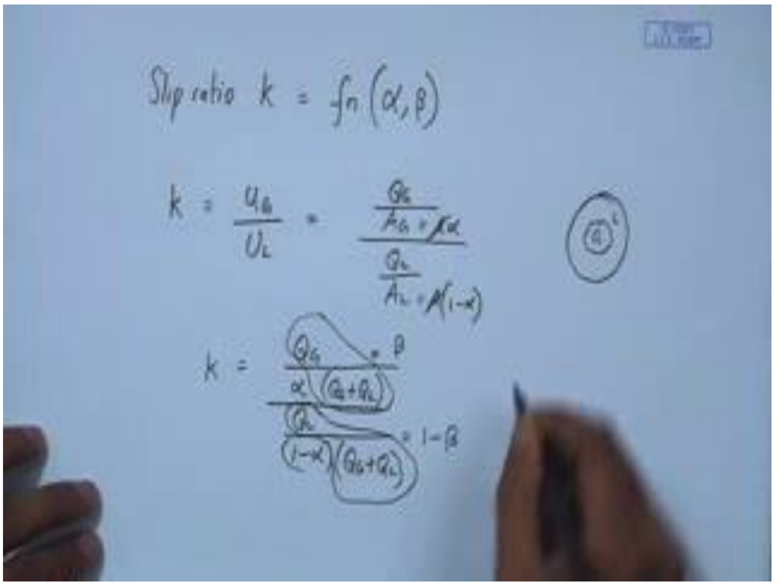

Now , we go to the second part, that is the slip ratio K, it need to be expressed as a function of A Alpha and Beta only. As we know K is the ratio of incentive velocities of gas phase divided by incentive velocities of liquid phase and this can be written as Q G by A G divided by Q L by A L where Q G and Q L are the volumetric chlorides of gas phase and liquid phase and A G and A L.

Suppose we are having a conduit, we are having a annular flow. This is the A L region and this is the gas region and this is the liquid region, the area the fraction of area, I am sorry, the area obtained by the gas region is termed as A G and the area obtained by the liquid region is termed as A L. This A G can be written as A into Alpha and A L can be written as A into 1 minus Alpha and this A and this A will be cancelled out. Thus we get K as Q G by Alpha divided by Q L by 1 minus Alpha and I divide both numerator and denominator with Q G plus Q L. All right and Now if we see this term, is as we have done in the, as we got in the first problem, this term can be written as Beta and this term can be written as 1 minus Beta.

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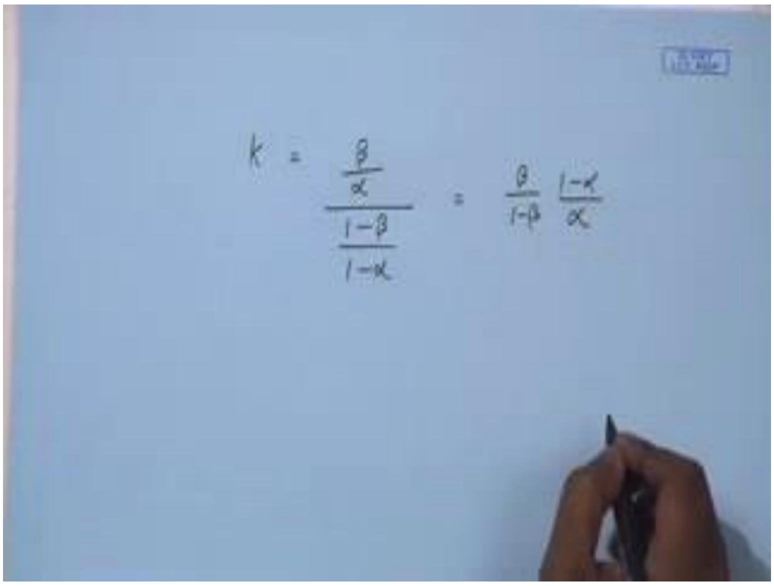

Therefore, we got K, this slip ratio as Beta by Alpha divided by 1 minus Beta by 1 minus Alpha and it can be further simplify to Beta by 1 minus Beta into 1 minus Alpha by Alpha.

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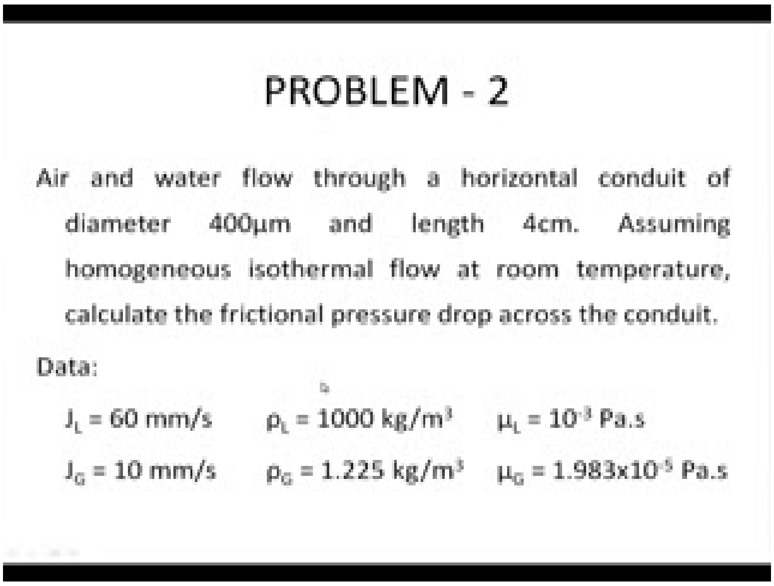

We go to the second problem; I will read the problem once. Air and water flow through a horizontal conduit of a diameter 400 micrometer and length 400 centimeter, assuming homogeneous isothermal flow at room temperature, calculate the frictional pressure drop across the conduit.

We have been provided with certain data that are the superficial velocities of liquid and gas phase, that is 60 millimeter per second and 10 millimeter per second and we have been provided with the phase densities as well as phase viscosities. Now before going into the frictional pressure drop estimation, I would like to tell you something.

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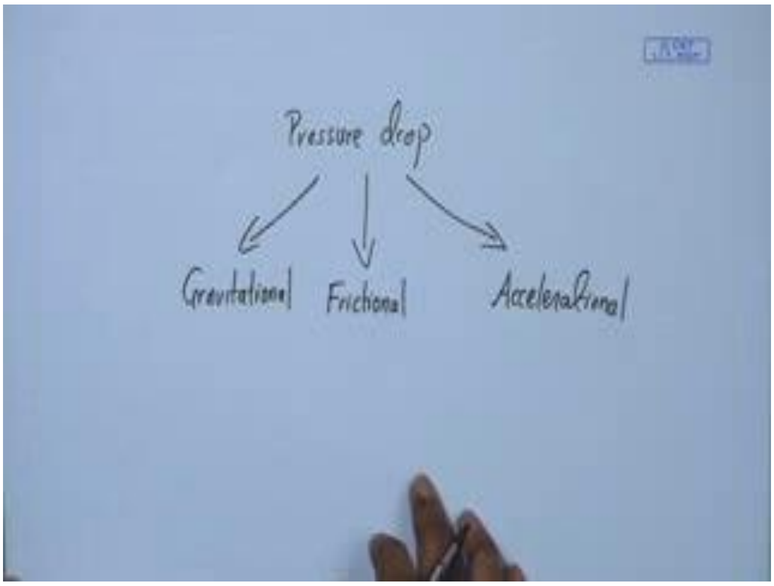

The pressure drop across a conduit can be categorized into 3 components, first one is gravitational pressure drop and second one is frictional pressure drop and the third one is accelerational pressure drop.

Here in this case, we are neglecting gravitational pressure drop because first of all, it is a horizontal conduit and secondly, the amount of liquid that is contained in the conduit is very, very small. So, we can neglect the gravitational pressure drop here and we will be calculating frictional pressure drop and talking about the accelerational pressure drop. We can neglect the accelarational pressure drop if there is no phase change as well as, there is no compressibility effects involved in the system.

Suppose if the relative change in specific volume across the specific volume happening across the system is greater than 5 percent, we have to consider acceleration pressure drop. If it is less than 5 percent, we will neglect accelerational pressure drop. So, for the time being, I am neglecting accelerational pressure drop. I am assuming that there is no accelarational pressure drop is involved because mainly there is no heating of conduit heating of conduit occurring, there is no phase change occurring.

So, I am taking only frictional pressure drop as of Now and at the end I will cross check whether of my assumption of neglecting acceleration pressure drop is right or wrong.

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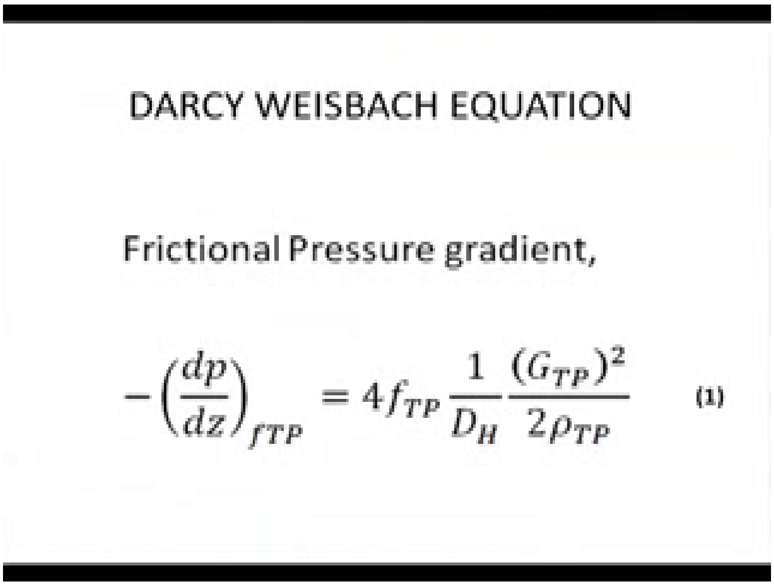

Now going to the frictional pressure gradient calculation, it can be calculated as Darcy Weisbach equation and the equation is shown in the screen diagram, while looking in the screen we can find out that there are plenty of what to say, plenty of unknown ns involved here. 1 is F T P, 1 is G T P and 1 is Rho T P and D H is a hydraulic diameter here. As it is circular channel, we can take the hydraulic diameter as they are diameter of the conduit and G T P.

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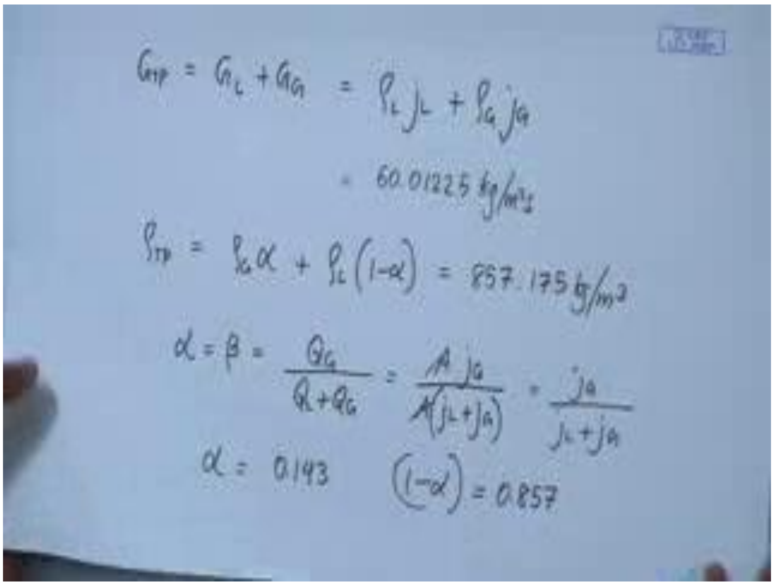

We need to find out the G T P as a total mass flux of the 2 phase mixture across a conduit. It is a sum of G L and G G that can be written as Rho L J L plus Rho G J G. Well J G and J L are the superficial velocities phase velocities and Rho L Rho G are the phase densities. We know all these values have been given and we got the values of G T P as 60 point 0 1 2 2 5 kilogram per meter square second. I am writing the value straight away because I am having a time restriction, that is why I am not doing the calculation, I have already calculated it.

Now , RHO T P, it can be found out as Rho G into Alpha plus Rho L, it is 1 minus Alpha. Alpha is an incentive volume factor as we are assuming it is a homogeneous flow model, we can take Alpha as Beta that is in a volumetric fraction and it can be written as Q G divided by Q L plus Q G by Q G and Q L are the phase volumetric chlorides. It can be written as A into J G by A into J L plus J G with J G J G and J L R is the superficial velocities of phases. Thus we can cancel out A and A From numerator and denominator. Thus it becomes J G by J L plus J G, we got the values of J G and J L. Thus we got the value of Alpha as 0.143 and 1 minus Alpha as 0.857 in. We substitute the value of Alpha and 1 minus Alpha here, we got the value of Rho T P as 857 0.175 kilogram per meter cube.

So, Now we got G T P,we got Rho T P, if we look at the equation, we see that only 1 unknown n is remaining, that is F T P.

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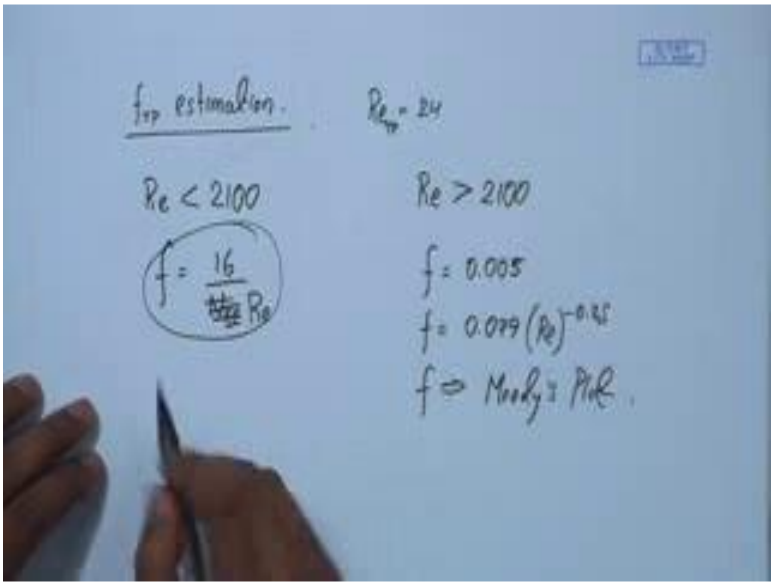

For the estimation of the F T P, where F is the fanning infraction factor to phase mixture, suppose it was a single phase Rho case, what we would have done? We would have found out the Reynolds number R E associated with the process and if R E comes below to 1 0 0, that is the laminar regime, we would have taken 16 by N R E as sorry 16 by R E as in the fan infraction factor value and if R E is greater than to 2 1 0 0, that is turbulent regime, we would have either took the value of F as a constant, that is 0 point 0 0 5, or we would have use the co relation 0 point 0 0 9 R E raised to minus point 2 5 or you would find the value of R E From Moody's plot.

Here I have already found out the value of R E and the value of R E is 24, I mean value of R E T P 2 phase Reynolds number is 24 and that is, comes in the laminar regime, but we cannot use this equation because this equation does not take into account, the wall interactions, the wall effects that are involved in the flow process.

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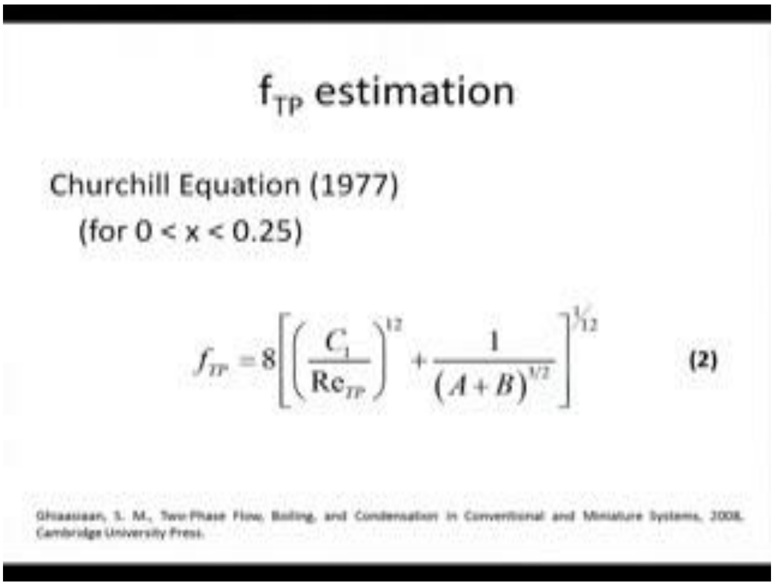

We are not taken this equation instead of that, we are going to another equation which is termed as the Churchill equation and this Churchill equation is applicable only for N X X value that ranges From 0 to 0 point 25, X value is the mass fraction value, mass quality.

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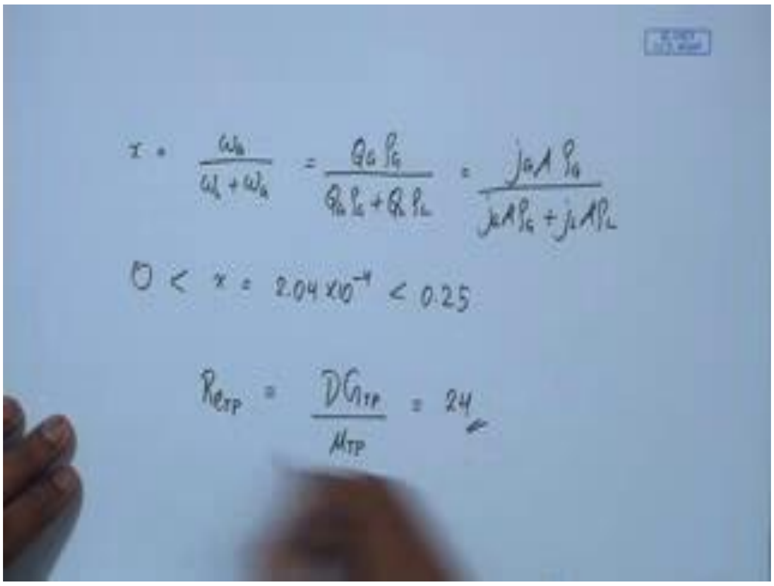

We need to calculate the mass quality, first of all whether to see if it is come in this range 0 to 0 point 25. So, mass quality X can be found out as W G by W L plus W G, here we are cancelling out the A value, Thus all the remaining value, we have already, it is already given J G value is given Rho G Rho L J L all are given. Thus we got the value of

E as 2 point 04 into to 10 raised to minus 4 and if we see this value, it comes in the range 0 point 25 and 0.

So, we can use Churchill equation for our calculation for the estimation of the F T F, if we look at the equation there are plenty of unknown ns here. There is an A, there is A B, there is R E T P, that are we have already found out and there is A C 1 for circular tubes or value of C 1 given as 8 and for R E S P estimation, we know that R E T P is equal to D into G T P by Mu T P we know the value of G D, we know the value of G T P.

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$$\mu_{TP} = \frac{\mu_G \mu_L}{\mu_G + x^{1.4}(\mu_L - \mu_G)} \qquad (3)$$

$$A = \left\{ \frac{1}{\sqrt{C_f}} \ln \left[\frac{1}{\left(\frac{7}{Re}\right)^{0.9} + 0.27\frac{\varepsilon_D}{D}} \right] \right\}^{16} \qquad B = \left(\frac{37530}{Re}\right)^{16} \qquad (4)$$

$\frac{\varepsilon_D}{D}$ = Dimensionless surface roughness

For circular channels, $C_1 = 8$ and $1/\sqrt{C_f} = 2.457$

Ghiaasiaan, S. M., Two-Phase Flow, Boiling, and Condensation in Conventional and Miniature Systems, 2008, Cambridge University Press.

We need to find out the value of Mu T P and Mu T P can be found out using equation 3. Here if we see, we have got the values of Mu G, we have got the values of Mu L and we got the value of X.

Substituting all these values, we will get the values of Mu T P, and if we substitute the values of Mu T P, here we will get the value of R E T P, as 24 and this comes in the laminar range and we substitute the value of R E T P, here we need to find out A and B value and find out A and B value, we got equations, that is given under equation 4 and B value we can straight From the R E value that we have got and a value for that, we need to find out 1 by root C T and for circular tubes, the value 1 by root C T, as given as 2.457 and we know the value of R E here. There is a term that includes component know n as epsilon D that is the roughness factor involved in the process.

Here we are assuming that it is a smooth conduit. So, we take the value of epsilon D as 0, Thus the whole term 0.27 epsilon D by D cancel out. So, we know the value of R E we know the value of 1 by root C T, Thus we got the value of A and B as.

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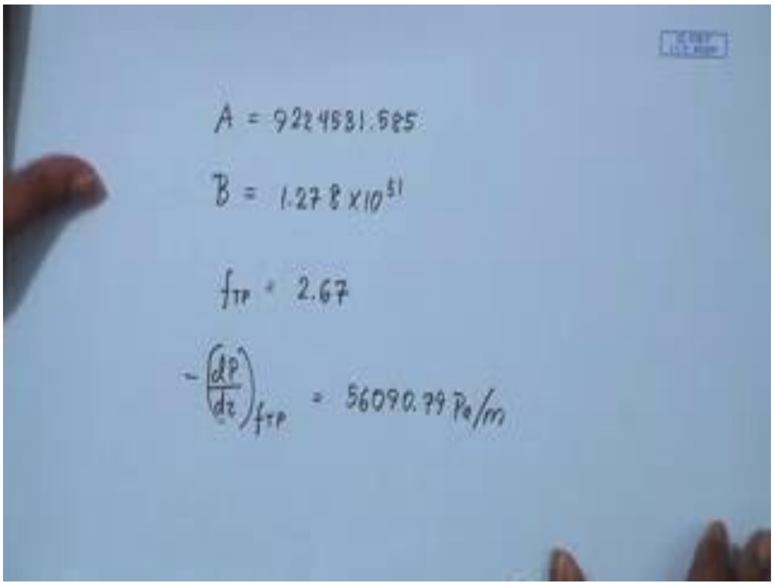

And Now I substituted all the values here, A B R E T P have got, I substitutes all the values and I got the value of fan infraction factor f T P as to 2.67 and I have substituted the value of fan infraction factor. Here in the Darcy Weisbach equation and I got the pressure gradient d P by d Z f TP as 56090.57, Pascal per meter and Now we need to find out the pressure drop value From the pressure gradient value.

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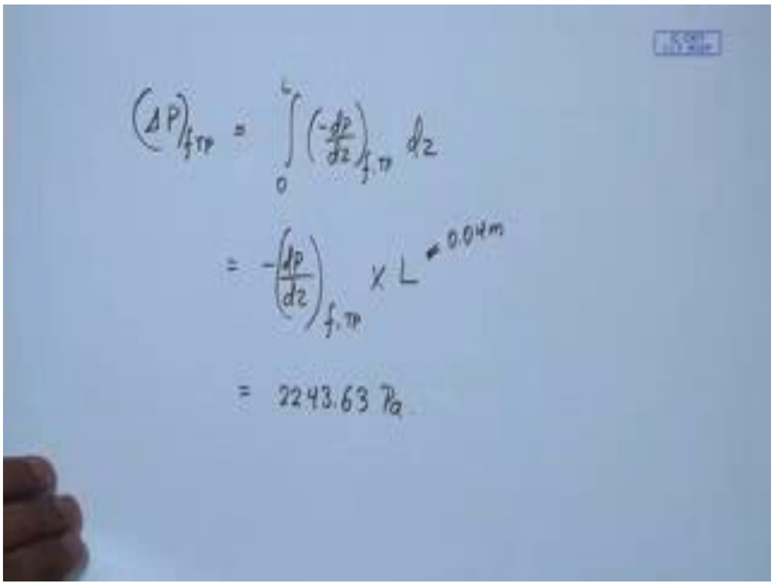

It can be founded using this equation using integration across the conduit length and this is equating minus d p by d z, f T P into L L, We know it is the value of the L is 4 centimeter that is 0 point 0 meter and by doing the calculation, we get the value of delta P, pressure drop as 2243.63 Pascal.

Now , we got the value of pressure drop using homogeneous flow model, Now initially I told you that, we have neglected the acceleration pressure drop value.

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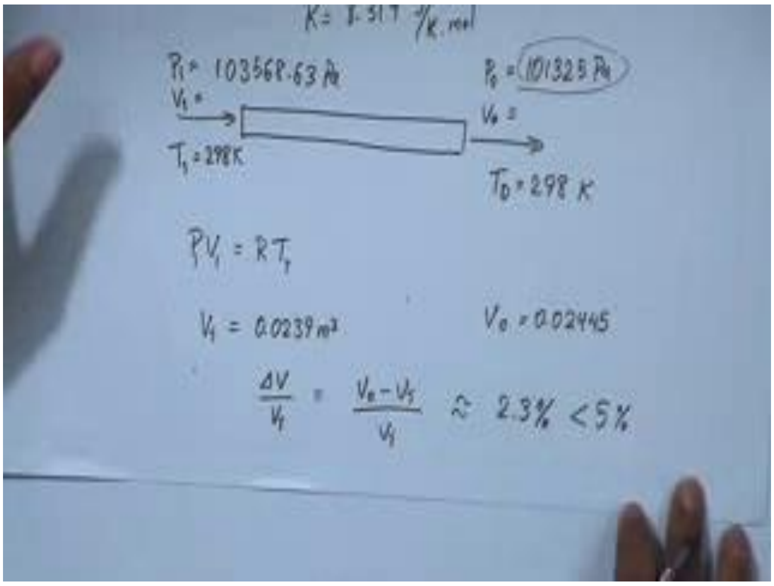

So, we need to cross check whether our assumption to neglect acceleration pressure drop value was right or wrong. So, in order to find out that I assumed that the inlet pressure is P I and the inlet specific volume is V I and the inlet temperature is the room temperature that is 2 98 Kelvin. The outlet temperature is the same because is the isothermal process it is 2 98 Kelvin outlet pressure. It is the atmospheric pressure, it is 1 0 3 2 5 Pascal outlet volume, we need to calculate V 0, we need to calculate V I and we need to check whether this relative variation is greater than 5 percent or less than 5 percent.

So, we have calculated the value of PV I and V 0 From ideal gas flow value of R, we know it is 8.314 joule per Kelvin mole and Now Substituting all the values I got the value of V I as 0.0239 meter cube, I got the value of V 0 as 0.02445 and I forgot to mention, I got the value of P I by adding the outlet pressure, that is the pressure drop and the values P I is 103568.63 Pascal .

Now , we have the V I, value we have the V 0 value, we need to find out the relative change in volume specific volume delta V by V I and I got it in 2.3 percent that is; obviously, less than 5 percent, Thus we are neglecting any kind of compressive effects and Thus we have assume that our assumption to neglect the acceleration pressure drop was right

(Refer Slide Time: 21:24)

CHISHOLM'S CORRELATION

$$\Phi_L^2 = 1 + \frac{C}{X} + \frac{1}{X^2}.$$

The values of coefficient C are (Chisholm, 1967) as follows:

Liquid	Gas	C
Turbulent	Turbulent	20
Viscous	Turbulent	12
Turbulent	Viscous	10
Viscous	Viscous	5

Ghiaasiaan, S. M., Two-Phase Flow, Boiling, and Condensation in Conventional and Miniature Systems, 2008, Cambridge University Press.

Now, we have found out the pressure drop using homogeneous flow model and I am repeating the same method, means repeating the same process that is, finding out the pressure drop across the conduit using another method that is the method that uses Martinelli parameter.

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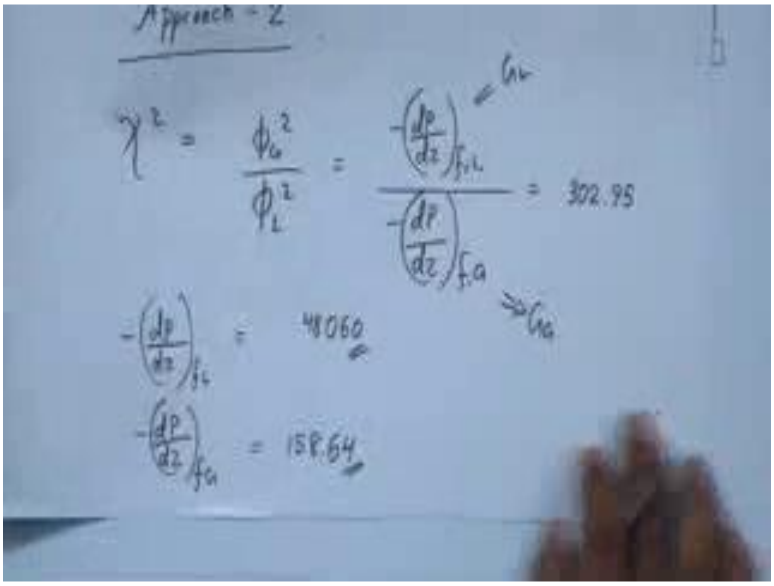

This is approach 2 here, Martinelli parameter Chi square is usually Phi G square Phi L square, where Phi G and Phi L are 2 phase multipliers, that can be written as minus D P by D Z F L and G, this term is the pressure drop that is involved when the liquid flows along through the conduit, at a mass flow rate at a mass flux of G L and this happens when gas flow alone, through the conduit at a mass flex of G G and we use the same procedure that is the Darcy Weisbach equation.

Darcy Weisbach equation plus the F T P estimation Churchill equation, we use the same thing for the calculation of single space pressure drops pressure gradients and we got the single phase pressure gradient values as we substitute these values here and we got the value of Chi square as 3 0 2 point 9 5 and Now we have a correlation know n as a Chisholms correlation. There we substitute the value of Chi square and Chi and we get the value of Phi L square that is the value of 2 phase multiplier and here also we got an unknown n, that is C for viscous cases, that is the case that we have encountering.

Now because the Reynolds number involved when liquid flows alone through the pipe as well as conduit as well as gas flows alone, through the conduit both comes under the laminar region the laminar regime.

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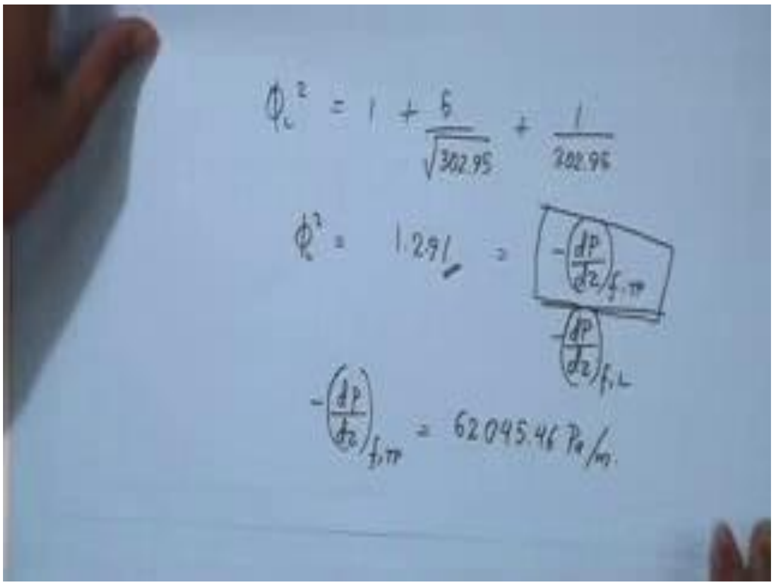

So, we take viscous case here, we take the value of C as 5 and we substitute the values in this equation, we got the value of Phi L square as 1.291. Now , what is Phi L square? Phi L square is minus D P by D Z F T P that is the Chisholms pressure drop involved when 2 phase mixture flows through the conduit by Chisholms pressure drop involved.

When liquid phase flow involved to the conduit at a mass flux G L and here we need to find out these value this is our pressure drop pressure gradient and this value we already know, we already found it out and the value was found out, we 4 8 0 6 0. We substitute the value here and we multiply 4 8 0 3 0, that is this value under this value and we got the 2 phase frictional pressure drop value as.

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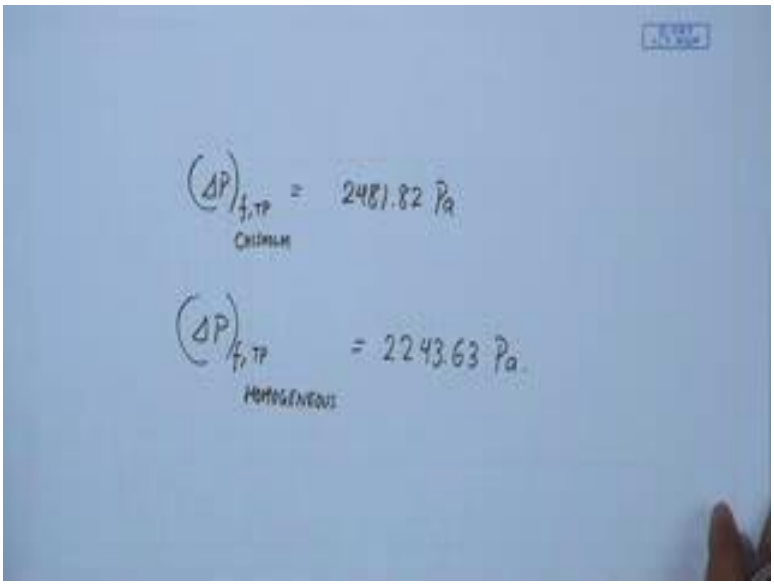

From this value we got the pressure drop value as we found out earlier as 2481.82 Pascal and this is the pressure drop value that is calculated using Chisholm's correlation.

We found out earlier that, the value of pressure drop calculated choosing homogeneous method was if we see, we can find out a small different between these two values. These two values were obtained form 2 different methods and this difference is basically due to fact that, in Chisholm's correlation, it is assumed that there is no interaction between the phases at the interphase and in homogeneous flow model. It is assumed that complete interactions occur at the phase interphase, complete in ration occurs between the phase at the interphase and these 2 are the extremes.

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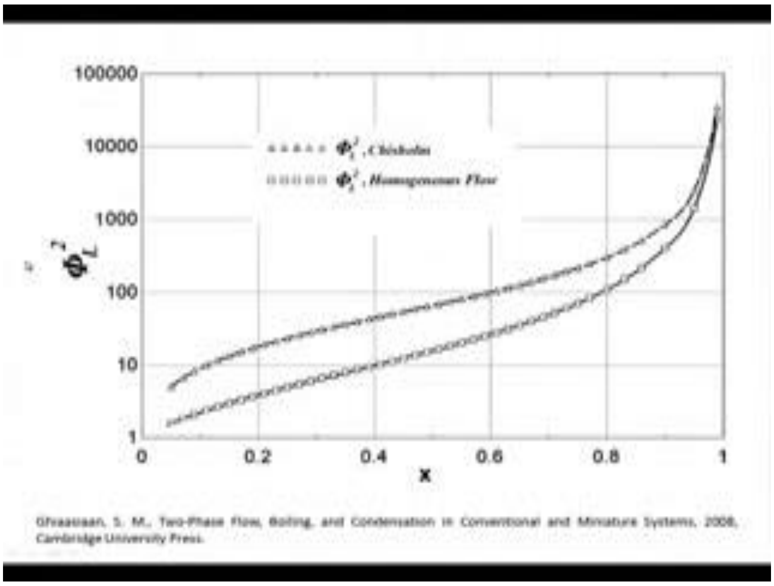

I will show you a graph, this has been taken From a literature and the top curve, it denotes the Phi L square that is 2 phase multiplier value for Chisholms correlation method and the bottom curve denotes the 2 phase multiplier value of obtain from homogeneous method and in this case at low mass quality values, we can see a deviation and in this deviation is due to the fact that I have explained earlier and in reality the pressure drop value will be somewhere in between these 2 values.

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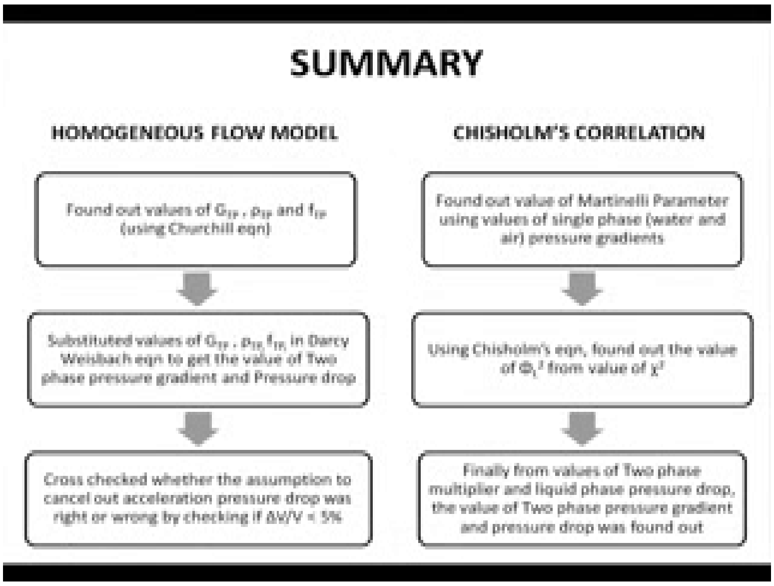

So, before winding up, I will just first summarize what I have,all done in the second problem, I have adopted 2 methods in order to calculate the pressure drop of 2 phase flow through a conduit and first method is homogeneous flow model method and second one is Chisholms correlation method and in the homogeneous flow model method.

I found out the values of G T P Rho T P F T P, but F T P value is found out using Churchill equation and I have substituted the values in the Darcy Weisbach equation to get the value of two phase pressure gradient and Thus the 2 phase pressure drop and then I cross check whether the assumption to cancel out acceleration pressure drop was right or wrong by checking if the relative change in specific volume was less than 5 percent and in Chisholms correlation method I found out the value of Martinelli parameter, using values of single phase that is water and air pressure gradient and From the value of Martinelli parameter using Chisholms correlations, I found out the value of 2 phase multiplier Phi L square and From there, From the values of the 2 phase multiplier as well as liquid phase pressure drop, I found out the 2 phase pressure gradient and pressure drop that is all From me Now Mr. (Refer Time: 28:02) will be explaining the basics of C F D analysis of 2 phase flow using (Refer Time: 28:06) software.

Thank you.