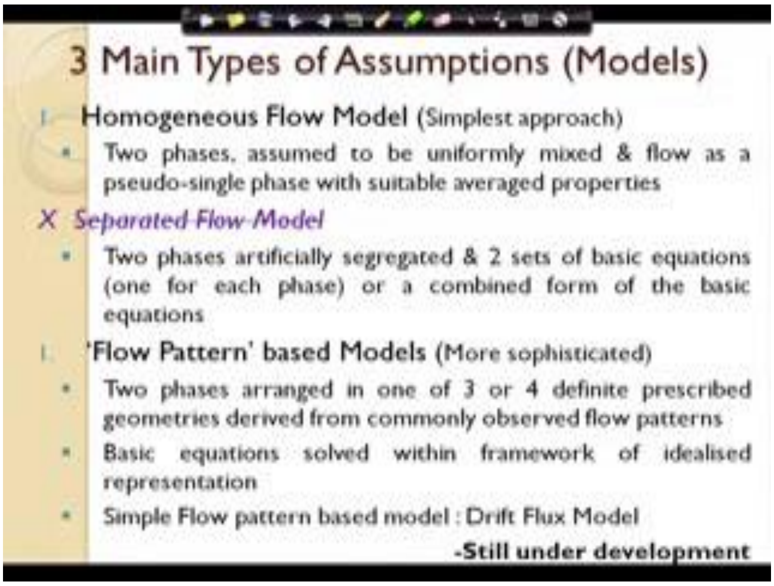
Adiabatic Two-Phase Flow and Flow Boiling in Microchannel
Prof. Gargi Das
Department of Chemical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 19
Theoretical Analysis of Two Phase Flow in Reduced Dimensions

(Refer Slide Time: 00:30)



3 Main Types of Assumptions (Models)

I. Homogeneous Flow Model (Simplest approach)
- Two phases, assumed to be uniformly mixed & flow as a pseudo-single phase with suitable averaged properties

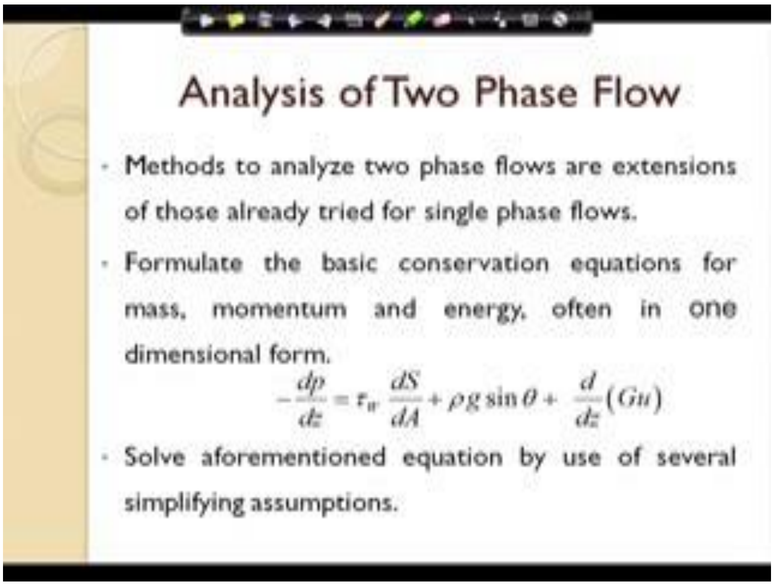
X ~~Separated Flow Model~~
- Two phases artificially segregated & 2 sets of basic equations (one for each phase) or a combined form of the basic equations

I. 'Flow Pattern' based Models (More sophisticated)
- Two phases arranged in one of 3 or 4 definite prescribed geometries derived from commonly observed flow patterns
- Basic equations solved within framework of idealised representation
- Simple Flow pattern based model : Drift Flux Model

-Still under development

Well, hello everybody. So, we have come to almost the end of this particular course. So, I was continuing my rather I will pick up my discussions which was continuing on the different analytical techniques to be used to predict hydrodynamics of flow.

(Refer Slide Time: 00:40)



Analysis of Two Phase Flow

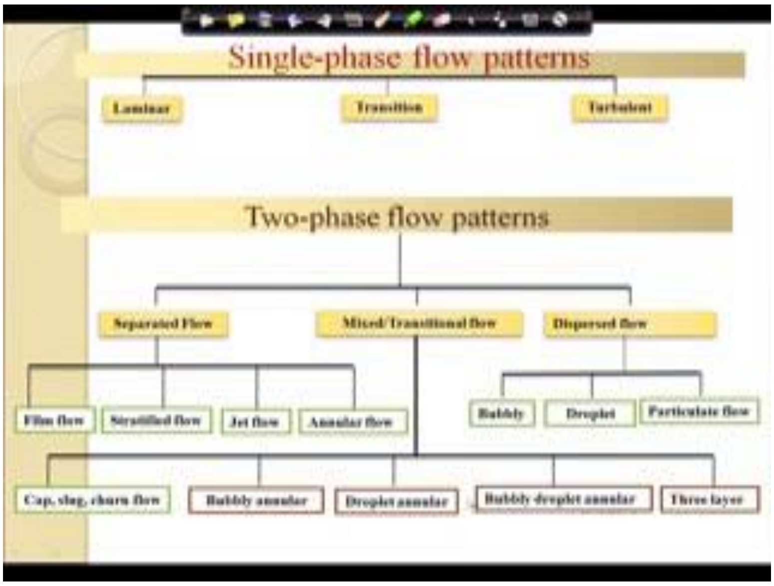
- Methods to analyze two phase flows are extensions of those already tried for single phase flows.
- Formulate the basic conservation equations for mass, momentum and energy, often in one dimensional form.

$$-\frac{dp}{dz} = \tau_w \frac{dS}{dA} + \rho g \sin\theta + \frac{d}{dz}(Gu)$$

- Solve aforementioned equation by use of several simplifying assumptions.

I was telling you that, mainly in order to solve the mass momentum and energy balance equations. We have to make several assumptions, now these assumptions which we should be making, that depends that has been decided after observing the different types of flow patterns which we come across during two phase flow.

(Refer Slide Time: 00:53).



Single-phase flow patterns

Laminar

Transition

Turbulent

Two-phase flow patterns

Separated Flow

Mixed/Transitional flow

Dispersed flow

Film flow

Stratified flow

Jet flow

Annular flow

Bubbly

Droplet

Particulate flow

Cap, slug, churn flow

Bubbly annular

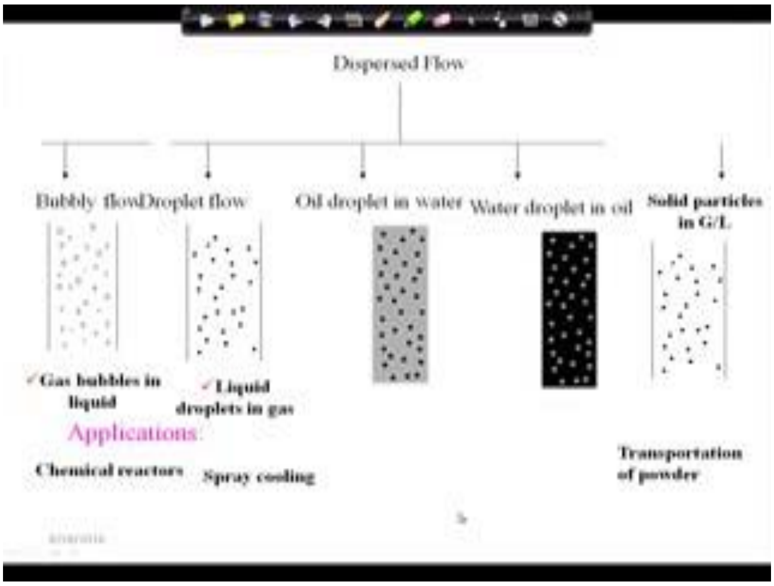
Droplet annular

Bubbly droplet annular

Three layer

Just like for single phase flow, we saw the momentum balance equation, deciding on fathered flow it is laminar or turbulent. For this is flow patterns also we try to develop a similar criteria.

(Refer Slide Time: 01:27)



Dispersed Flow

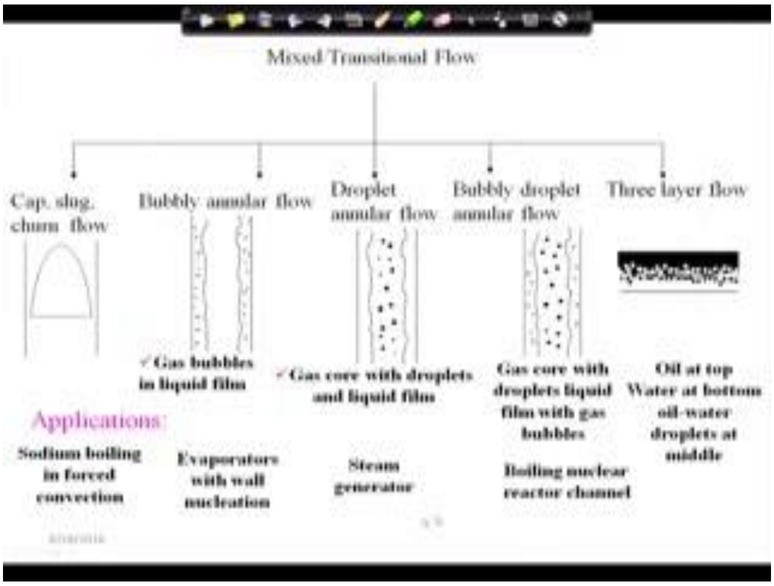
Bubbly flow
Droplet flow
Oil droplet in water
Water droplet in oil
Solid particles in G/L

✓**Gas bubbles in liquid**
✓**Liquid droplets in gas**

Applications:

Chemical reactors
Spray cooling
Transportation of powder

(Refer Slide Time: 01:30)



Mixed Transitional Flow

Cap, slug, churn flow
Bubbly annular flow
Droplet annular flow
Bubbly droplet annular flow
Three layer flow

✓**Gas bubbles in liquid film**
✓**Gas core with droplets and liquid film**
Gas core with droplets liquid film with gas bubbles
Oil at top Water at bottom oil-water droplets at middle

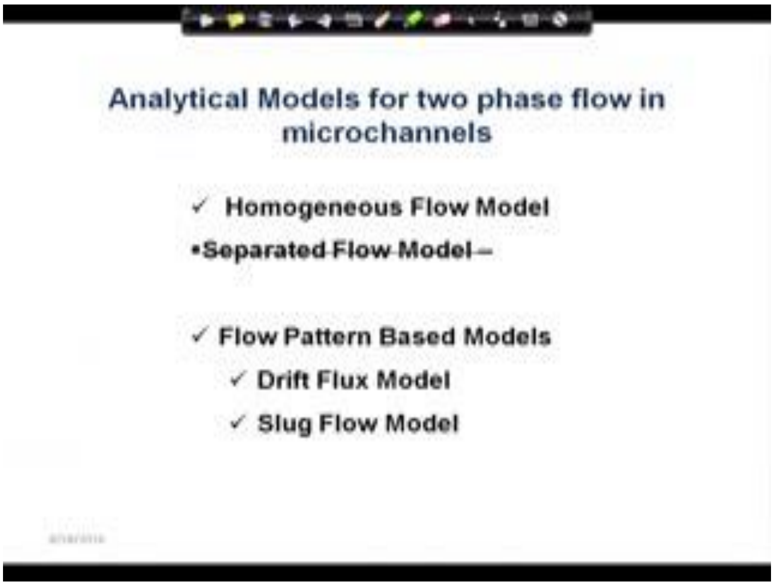
Applications:

Sodium boiling in forced convection
Evaporators with wall nucleation
Steam generator
Boiling nuclear reactor channel

And we observed that, if we go through all the flow patterns, more or less that we have discussed particularly in macro substance, we find that we can classify the entire set into a separated flow pattern and dispersed flow pattern and the large range of mix flow patterns, which can be or rather this schematics are shows as follows.

So, from here it is very evident that, as we come down to the micro channels, we will primarily be dealing with the discussed and more importantly, with the mixed or the transitional flow patterns.

(Refer Slide Time: 01:48)



Analytical Models for two phase flow in microchannels

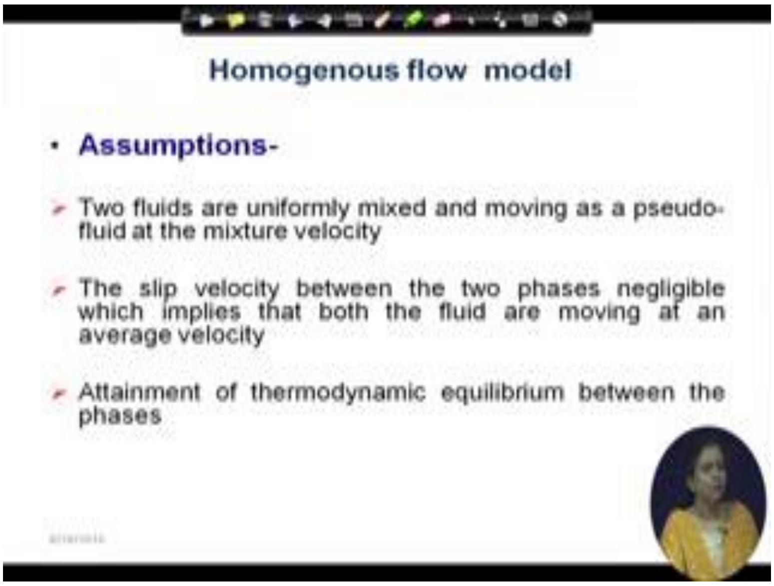
- ✓ Homogeneous Flow Model
- ~~Separated Flow Model –~~

- ✓ Flow Pattern Based Models
  - ✓ Drift Flux Model
  - ✓ Slug Flow Model

Accordingly, what we have decided is that, in this particular lecture series, we shall be discussing the homogeneous flow model which assumes the two fluids to be completely mixed and then after that, we will be going to the flow patterned based model and here one of this simplest flow patterned based model is the drift flux model, which is used more or less frequently in micro systems. So, will be dealing with it the drift flux model and then since slug flow is the most predominate flow pattern we will be dealing with the simplified slug flow model to end it up.

And while I go through the analysis, I will be taking up cases for adiabatic gas liquid flows as well as cases or rather how the equations, they change when we are dealing with your flow boiling in micro systems.

(Refer Slide Time: 02:43)



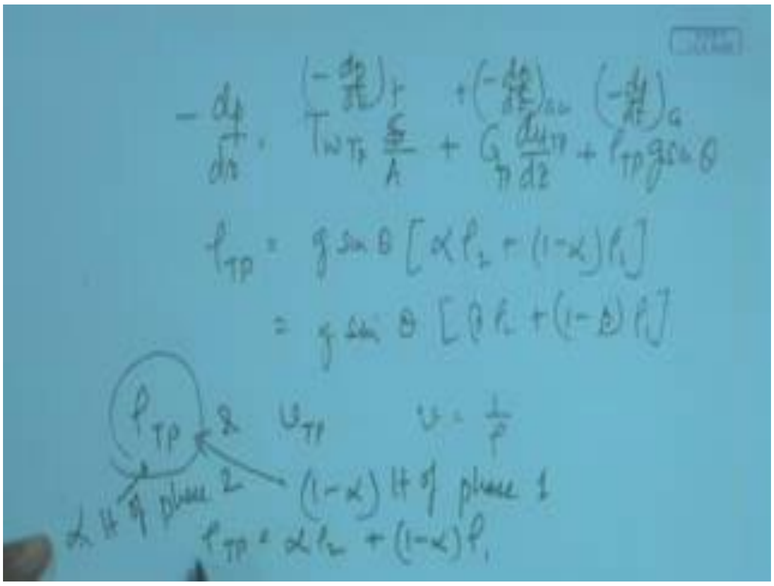
Homogenous flow model

- **Assumptions-**
  - Two fluids are uniformly mixed and moving as a pseudo-fluid at the mixture velocity
  - The slip velocity between the two phases negligible which implies that both the fluid are moving at an average velocity
  - Attainment of thermodynamic equilibrium between the phases

So, now with the Homogeneous flow model, now in this particular model, as we know for what do we assume? We assume that the two fluids are uniformly mixed and they have flowing as if pseudo fluid at the uniform mixture. Now what does this imply? This implies that U L S must rather U L, it is not U L S it is U L, and this is equal to U G which is equal to U T P. Is not it? And naturally if the two phases the Incitu velocities, they are flowing at the same velocity. It automatically implies, that the slip between the 2 which is S which is equal to U G by U L, that is naturally equal to 1,which again implies that Alpha should be equal to Beta. Under this particular conditions and along with that it also implies that there is thermodynamic equilibrium between the 2 phases.

With this if we develop the model, what do we find? We find that in this particular case, we find, where does the equation come down? The equation, the next thing which, we from here the model which we get from here is that, so, the equation which we can develop from here is the homogeneous flow equation, where we get the pressure gradient minus dp dz.

(Refer Slide Time: 04:32)



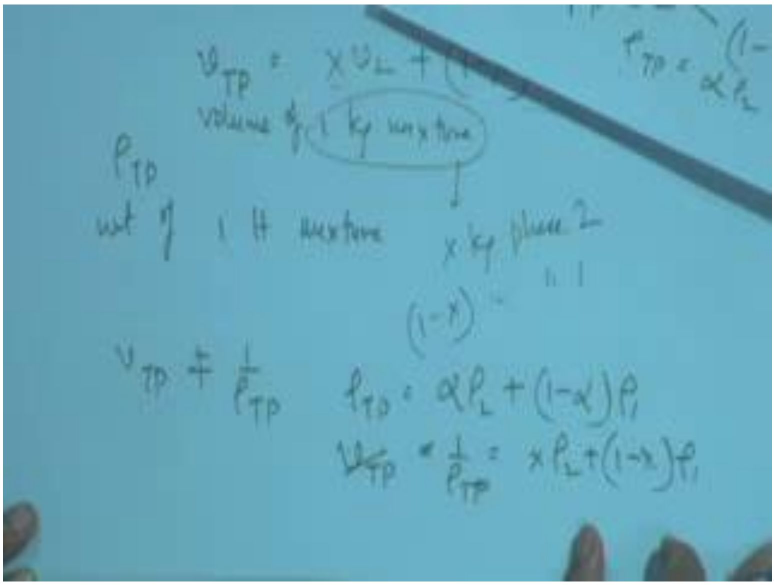
It is equal to Tau w 2 phase plus S by A plus G du dz, writes 2 phase density at 2 phase mass flux and du dt plus Rho T P G sin Theta.

Now in this particular case, what is Rho T P equal to? Rho T P is naturally equal to g Sin Theta into Alpha Rho 2 plus 1 minus Alpha Rho 1, where Alpha is the Incitu void fraction, and in this particular case this is since Alpha equals to Beta, we get this as Beta Rho 2 plus 1 minus beta Rho 1.

And we can also, we are fine. So, therefore, this comprises of the gravitational pressure gradient and this is nothing but the acceleration pressure gradient and this is the frictional pressure gradient. So, therefore, from here what do we get? We get from here. So, therefore, and there is something very important about 2 phase flow which you should be knowing, which tells you that Rho T P and V T P, they are not exactly reciprocal of one another or in other words what I mean is that, for any particular single phase flow, we know that the specific volume is nothing, but the inverse or reciprocal of density.

But if we consider a 2 phase mixture, even under homogeneous flow conditions also, what do we find? We find that Rho T P, it refers to the weight of say 1 meter or 1 liter cube of the mixture. So, naturally this gives you rather it comprises of say, in that 1 meter of a mixture we have Alpha liter of phase 2 and we have 1 minus Alpha liter of phase 1 and therefore, the total weight of alpha liters of phase 2 is what? It is naturally Alpha into Rho 2 and the total weight of 1 minus Alpha liters of phase 1 is 1 minus Alpha into Rho 1 and therefore, Rho T P is given by this.

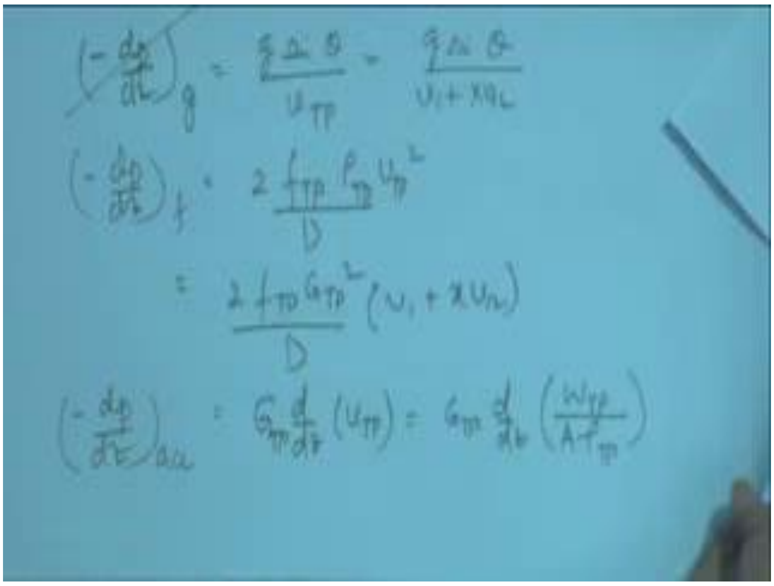
(Refer Slide Time: 07:31)



On the other hand, if we considered V T P, what do we get? We find that V T P, it is the volume of 1 K G of the mixture. Therefore, while Rho T P, it was the weight of 1 liter mixture or may be 1 meter cube mixture, this is the volume of 1 kg mixture. So, naturally what does it imply? This means that, in this 1 kg mixture, there is X kg phase 2 and there is 1 minus X kg phase 1. So, the weight of this 1 kg phase 2, this is going to be X into V 2 and this is going to be 1 minus X into V 1.

So, therefore, we find out that while V T P is expressed in terms of the quality of the mixture, Rho T P is expressed in terms of the volume fraction and therefore, it is quite evident that Rho T P or other V T P, it is not the reciprocal of Rho T P. In other words, the expression of Rho T P is in terms of void fraction, where as the expression of rather 1 by Rho T P, this is in terms of your quality. So, therefore, this is 1 particular basic thing, which you need to remember in 2 phase flow. This is something very important. We are quite used to thinking that the specific volume is the reciprocal of density, but that does not matter or that does not happen in this particular case.

(Refer Slide Time: 09:45)



$$\left(-\frac{dp}{dz}\right)_g = \frac{g\sin\theta}{v_{TP}} = \frac{g\sin\theta}{v_1 + x v_{12}}$$

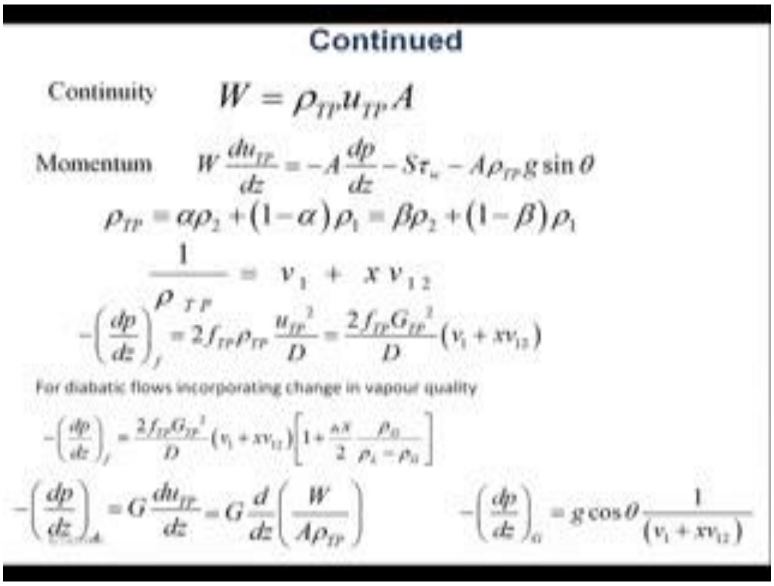
$$\left(-\frac{dp}{dz}\right)_f = \frac{2 f_{TP}\,\rho_{TP}\,u_{TP}^2}{D}$$

$$= \frac{2 f_{TP}\,G_{TP}^2}{D}\left(v_1 + x v_{12}\right)$$

$$\left(-\frac{dp}{dz}\right)_{acc} = G_{TP}\frac{d}{dz}\left(u_{TP}\right) = G_{TP}\frac{d}{dz}\left(\frac{W_{TP}}{A\rho_{TP}}\right)$$

So, therefore, regarding the gravitational pressure gradient, what do we find? Gravitational pressure gradient, it can be expressed either in terms of the volume fraction and if there is large amount of change there.

(Refer Slide Time: 10:00)



Continued

Continuity $W = \rho_{TP} u_{TP} A$

Momentum $W\frac{du_{TP}}{dz} = -A\frac{dp}{dz} - S\tau_w - A\rho_{TP} g\sin\theta$

$$\rho_{TP} = \alpha\rho_2 + (1-\alpha)\rho_1 = \beta\rho_2 + (1-\beta)\rho_1$$

$$\frac{1}{\rho_{TP}} = v_1 + x v_{12}$$

$$-\left(\frac{dp}{dz}\right)_f = 2 f_{TP}\rho_{TP}\frac{u_{TP}^2}{D} = \frac{2 f_{TP} G_{TP}^2}{D}\left(v_1 + x v_{12}\right)$$

For diabatic flows incorporating change in vapour quality

$$-\left(\frac{dp}{dz}\right)_f = \frac{2 f_{TP} G_{TP}^2}{D}\left(v_1 + x v_{12}\right)\left[1 + \frac{\Delta x}{2}\frac{\rho_G}{\rho_L - \rho_G}\right]$$

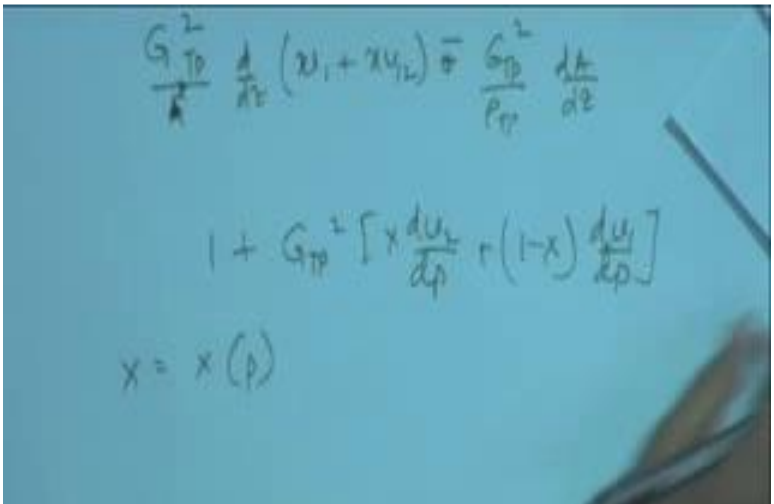
$$-\left(\frac{dp}{dz}\right)_A = G\frac{du_{TP}}{dz} = G\frac{d}{dz}\left(\frac{W}{A\rho_{TP}}\right) \qquad -\left(\frac{dp}{dz}\right)_G = g\cos\theta\frac{1}{\left(v_1 + x v_{12}\right)}$$

Then if the void fraction if changes to a large extent. A better way of expressing it is G Sin Theta by V T P, which gives you G Sin Theta by V 1 plus X V 1 2. Now regarding the (Refer Time: 10:25), rather we go to the frictional pressure gradient. Now what do we find in the frictional pressure gradient? Naturally this frictional pressure gradient, this is equal to 2fTP

Rho T P I can write it down, U T P square by D, where this is equal to 2 f T P G T P square by D into V T P, which can otherwise be written down as V 1, the V T P part can be written down in this particular form.

Now remember 1 thing, when we are dealing with micro systems gravitational pressure gradient is usually not there. So, it is the frictional pressure gradient, which is there and the acceleration pressure gradient, which is there. What is the acceleration pressure gradient in this particular case? It is naturally G T P T P means 2 phase of U T P. Why does U T P vary? Can you tell me, it can vary if the area varies, which is true for single phase flow also. Which can also vary if the densities of the true phases they vary or if the quality of the 2 phase mixture, it varies, accordingly we find that V T P, it can or rather this particular term, this can be expanded as your G T P into W T P by A 1 by Rho T P plus G T P W T P W T P by Rho T P D D Z, 1 by A, which can again be expanded as G T P square into d d z of V 1 plus X V 1 2, X V 1 2 minus G T P square by Rho T P da dz..

(Refer Slide Time: 12:29)



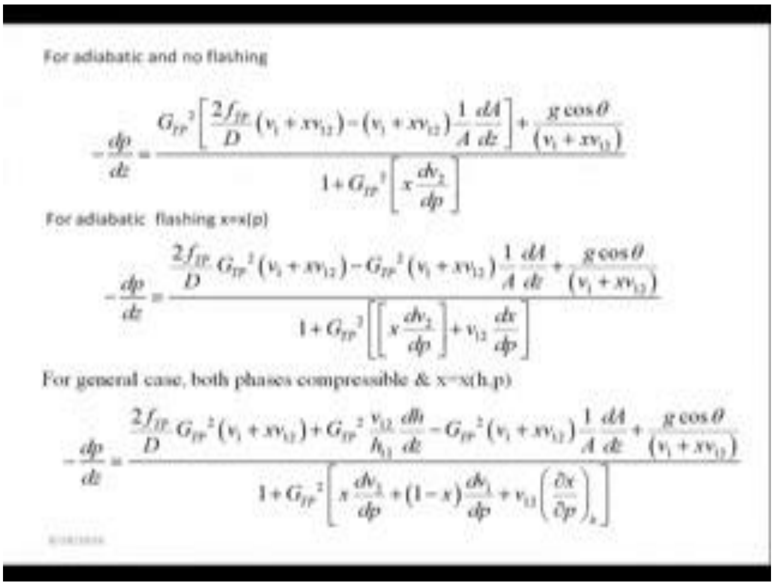
$$\frac{G_{TP}^2}{A}\frac{d}{dz}\left(v_1 + x v_{12}\right) - \frac{G_{TP}^2}{\rho_{TP}}\frac{dA}{dz}$$

$$1 + G_{TP}^2\left[x\frac{dv_2}{dp} + (1-x)\frac{dv_1}{dp}\right]$$

$$x = x(p)$$

So, we can write it down in this particular form, where and we have written it down here where, we find that there is, when we consider adiabatic and there is no flashing.

(Refer Slide Time: 13:06)



For adiabatic and no flashing

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

For adiabatic flashing x=x(p)

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

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

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

So, in that case what happens this is the frictional pressure gradient; this is the acceleration pressure gradient. In this case acceleration, it occurs. Firstly, due to a change in area if it is there, mostly there is no area, change this term goes away and then there is one more term which happens because the specific volume, it changes with pressure. So, due to this also and additional pressure gradient happens and accordingly we find for adiabatic and no flashing case we find that the pressure gradient can be written down by this particular expression.

Now, in this case I like to mention that, we assume that only the gas phase is compressible. It is usually the case, we other phase which is the solid or the liquid phase is usually not compressible, and we generally do not deal with two phase flows, but to both the phases compressible because, if you have a gas mixture, that is never the 2 phase mixture that is always the miscible mixture and liquids can behave as compressible fluid only under very large pressure gradients, if that part is there then in that case along with the denominator we have another additional term, apart from this particular term we have another additional term to take into account, the comprehensibility of the liquid phase or this was for adiabatic and no flashing.

Now, suppose the pressure gradient is so large that even if you are not giving any heat also there is some amount of depressurization and may be due to that some amount of liquid it gets converted into its vapor. So, therefore, in that case what happens at the flow proceeds? The X the quality of the mixture if changes and that quality, change occurs just because there is a change in pressure. So, therefore, in this particular case when I was talking about finding out the acceleration pressure gradient in this particular case, this Rho T P which is nothing, but V 1 plus C V 1 2. Until this particular case, we had assumed that V T is the function of your pressure and that is why it is changing with Z X also we comes a function of pressure and that also starts changing with X sorry with Z.

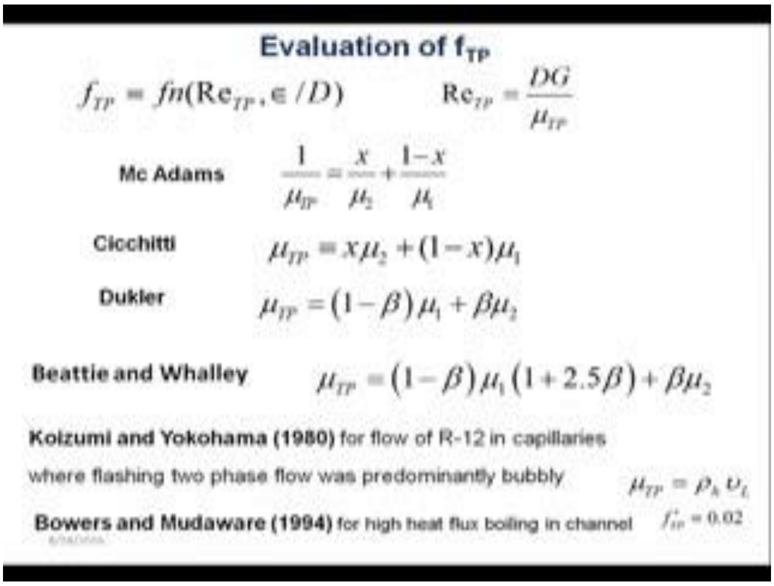
And so, naturally in this case we need to incorporate D X D Z, which is nothing, but D X D P into D P D Z. So, this gives me an additional term in the denominator. In this case and suppose we take the most general case where it is that, both the phases are compressible and we have a heat input, where flow boiling occurs and along with that, it is in the micro channel. So, good amount of pressure gradient also occurs.

So, with all these if we combine then we find that the general expression, it is expressed again as the component of frictional pressure gradient. That is from the acceleration pressure gradient; there is long particular component due to the change in quality due to the heat and flux. There is 1 particular component due to area change. If at all it is there, that is the gravitational component and in the denominator part it comprises of terms due to the comprehensibility of the 2 phases as a result of pressure gradient along the flow and also the change in quality due to the flashing of the mixture and as a result of which exchanges.

So, therefore, we are considered all the cases for adiabatic no flashing, that again adiabatic flashing for Q equal to or the heat input is zero, but any how the change in quality occurs. This can occur in micro channels when it is flowing under significant pressure gradient and then we have also considered the general case. Now if you look at the equations very minutely, what do you find? You find that, all the equations almost you know everything G T P. So, it is a mass flux, if you know the mass flow rate and the area you can find it out, but the change in quality along where due to heat flux and the change in quality due to the depressurization can be obtained.

The comprehensibility of the 2 phases once you know the phases, you can find out the physical properties from suitable tables and there. So, this can be found out and so, you know all the terms which are available to find out pressure gradient for any particular case which you consider the only unknown which we find is the 2 phase friction pattern.

(Refer Slide Time: 18:30)



Evaluation of f_{TP}

$f_{TP} = fn(\mathrm{Re}_{TP}, \in / D)$ $\quad \mathrm{Re}_{TP} = \frac{DG}{\mu_{TP}}$

Mc Adams $\quad \frac{1}{\mu_{TP}} = \frac{x}{\mu_2} + \frac{1-x}{\mu_1}$

Cicchitti $\quad \mu_{TP} = x\mu_2 + (1-x)\mu_1$

Dukler $\quad \mu_{TP} = (1-\beta)\mu_1 + \beta\mu_2$

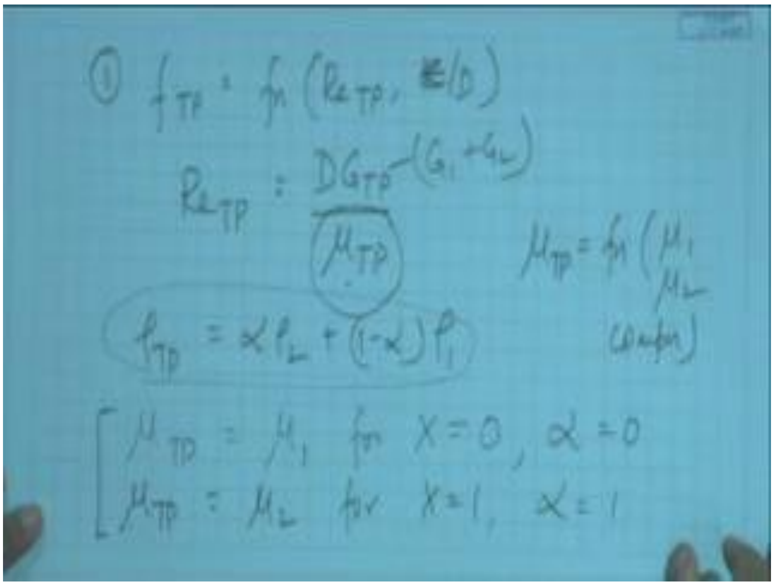
Beattie and Whalley $\quad \mu_{TP} = (1-\beta)\mu_1(1+2.5\beta) + \beta\mu_2$

Koizumi and Yokohama (1980) for flow of R-12 in capillaries where flashing two phase flow was predominantly bubbly $\quad \mu_{TP} = \rho_k \upsilon_L$

Bowers and Mudaware (1994) for high heat flux boiling in channel $\quad f_{TP} = 0.02$

Now, how to find it out rather, how to evaluate that 2 phase friction pattern? We know that from knowledge of single phase flow and as well as 2 phase flow in macro systems, naturally the way to find out F T P will again take some Q from the general practices in macro systems.

(Refer Slide Time: 18:52)



① $f_{TP} = fn(Re_{TP}, \epsilon/D)$

$Re_{TP} = \frac{DG_{TP}}{\boxed{\mu_{TP}}}$ $(G_1 + G_L)$

$\mu_{TP} = fn(\mu_1, \mu_L, \text{condn})$

$\boxed{\rho_{TP} = \alpha\rho_L + (1-\alpha)\rho_1}$

$\mu_{TP} = \mu_1$ for $X = 0$, $\alpha = 0$

$\mu_{TP} = \mu_L$ for $X = 1$, $\alpha = 1$

In macro systems, 1 conventional thing to assume is that f T P, it is a function of Reynolds number for the 2 phase and it is a function of sorry epsilon by D where epsilon is the or rather this is the relative roughness factor.

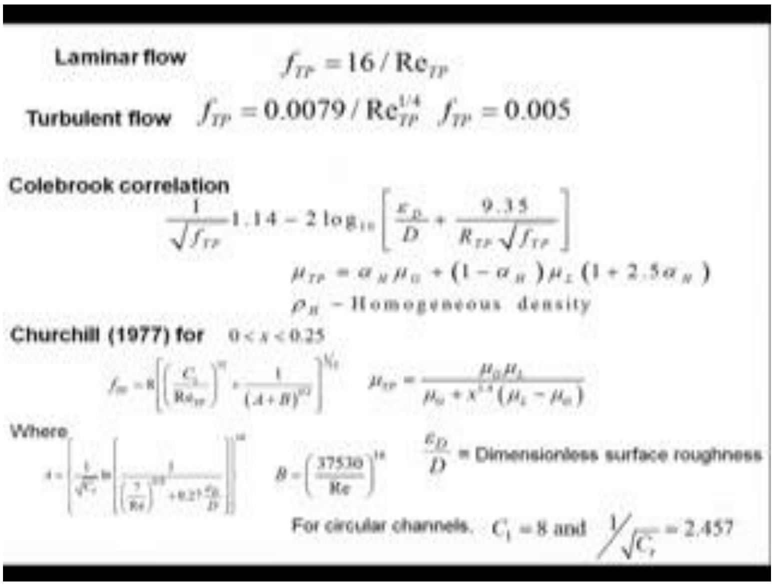
Now, how do we define R e T P for the 2 phase system? R e T P for the 2 phase system is naturally D G T P into Mu T P, we know D G T P, I have already mentioned this is G 1 plus G 2 diameter of the pipe, we know. Only thing which we do not know is the mixture viscosity. Here I would like to mention that, if it is Rho T P then, it can very well be expressed in terms of a suitable average of the individual mixture densities expressed it, expressed as a function of the incite void fraction, but remember 1 thing Mu T P it is not the mixture property. This Rho T P is the same, probably the mixture is flowing or this and under that condition it hardly matters, but Mu T P is a flow property.

Therefore it depends upon the shear which occurs during the flow and therefore, replacing to Mu T P in the way Rho T P are, be density of the 2 phase mixture is expressed will not be correct and unless we have a good knowledge about the type of shear which occurs. It is very difficult to find out the analytical expression to find if estimated Mu T P. So, what is the conventional thing which is done? Conventional thing is, we propose some averaging loss, some suitable averaging loss for Mu T P in terms of composition and ensure that Mu T P reduces to Mu or phase 1 for phase for the quality of phase 1 to be 1 or rather X equals to 0 and Alpha equals to 0 and Mu T P equals Mu 2 for X equals to 1 and Alpha equals to 1 whatever be the case.

So, therefore, these are the true constraints based on which a proper Mu T P is expressed in terms of Mu 1 Mu T P and composition which can be either the volume fraction or the mass fraction. Accordingly in macro systems what do we find? We find that several Mu T P expressions have been proposed and they have also been tried in macro channels and people have observed that for some cases, the Duckler expression is good, a few cases the Cicchitti expression is not bad, but in micro channels additional or rather of few other averaging loss and Mu T P has been provided and Beattie and Whalley's correlation is one such important thing.

And also we find that during boiling 2 phase flow, a few other correlations have also been proposed. This has been proposed based on that fact that R 12 is flowing in capillaries and due to flashing the 2 phase flow was predominantly bubbly. So, therefore, Mu T P has been expressed in terms of a you are homogeneous mixture density and the specific volume of the liquid and then for high flux boiling in channel again a second correlation has been proposed. Now once more I would like to emphasis that it is not a mass that you should remember the correlations, the only 2 correlations which you should be remembering for this particular class is the Dukler correlations, which is pretty easy and the Beattie and Whalley correlation which is basically the Dukler correlation with 1 particular term of 1 plus 2 point 5 beta. Now different people, they have worked to get different types of correlations and then have suggested different things.

(Refer Slide Time: 23:03)



Laminar flow $f_{TP}=16/\mathrm{Re}_{TP}$

Turbulent flow $f_{TP}=0.0079/\mathrm{Re}_{TP}^{1/4}$ $f_{TP}=0.005$

Colebrook correlation

$$\frac{1}{\sqrt{f_{TP}}}1.14-2\log_{10}\left[\frac{\varepsilon_D}{D}+\frac{9.35}{R_{TP}\sqrt{f_{TP}}}\right]$$

$$\mu_{TP}=\alpha_H\mu_G+(1-\alpha_H)\mu_L(1+2.5\alpha_H)$$

ρ_H – Homogeneous density

Churchill (1977) for $0<x<0.25$

$$f_{TP}=8\left[\left(\frac{C_1}{\mathrm{Re}_{TP}}\right)^{12}+\frac{1}{(A+B)^{3/2}}\right]^{1/12}\qquad \mu_{TP}=\frac{\mu_G\mu_L}{\mu_G+x^{1.4}(\mu_L-\mu_G)}$$

Where

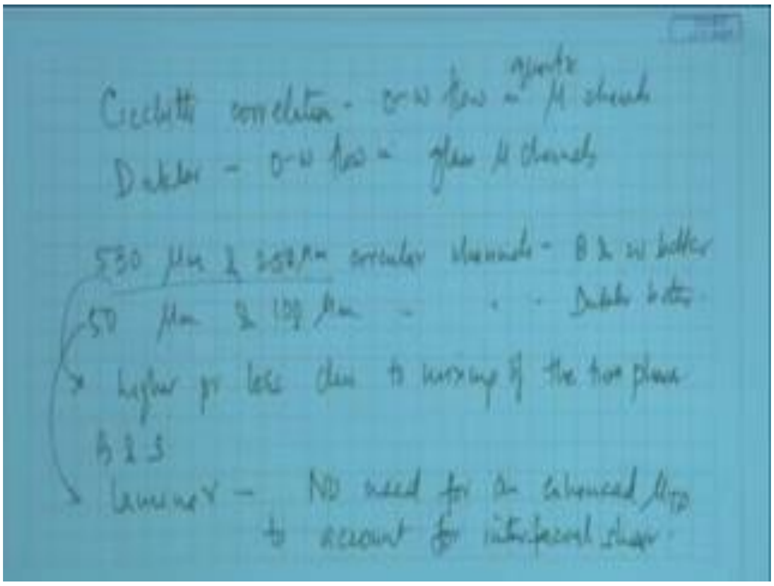
$$A=\left[\frac{1}{\sqrt{C_f}}\ln\left[\frac{1}{\left(\frac{7}{\mathrm{Re}}\right)^{0.9}+0.27\frac{\varepsilon_D}{D}}\right]\right]^{16}\qquad B=\left(\frac{37530}{\mathrm{Re}}\right)^{16}$$

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

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

For example in that oil water flow, it is oil water flow paper for under certain conditions they said that the Beattie and Whalley correlation is better and for some other conditions people said that the Dukler correlation, it is better.

(Refer Slide Time: 23:34)



Cicchitti correlation - o-w flow in quartz μ channels

Dukler - o-w flow in glass μ channels

530 μm & 558 μm circular channels - B & W better

50 μm & 100 μm - " " Dukler better

→ higher pr loss due to mixing of the two phase

B & S

→ laminar - No need for an enhanced μ_{TP} to account for interfacial shear

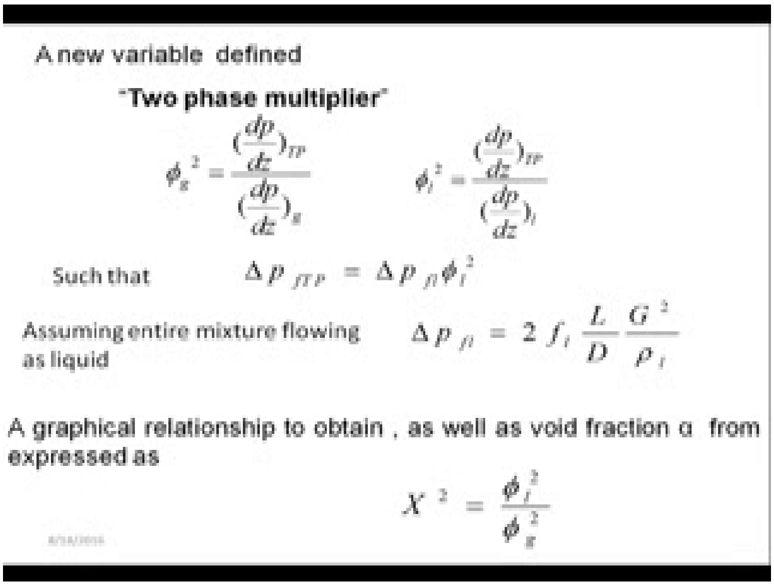
Now, it is now for example, then this oil water flows if you notice people have said that Cichitti correlation, this was better for oil water flow in micro channels, where as the Dukler correlation, this was good for oil water flow in glass micro channels. Well this was in what is micro channels. And then again some, there were other people who said that Beattie and Whalley's correlation, it is suitable for a large number of cases for example, if you observe the experimental results which I had shown, you will find that for 5 40 and for 2 50 micro meters circular channels, Beattie and Whaley correlation was better, whereas for 50 and 100 micro meter channel the Duckler correlation was better.

Now, I will definitely not expect you to remember all this things, but it is very important to know that thrice. So, many correlations have been proposed and thrice under different circumstances different correlations worked better. Just observe the 2 most common correlations and due to Dukler and Beattie and Whalley, if you observe to be expressions you can understand that for this same flow rates Beattie and Whalley correlation will give up higher effective to shows viscosity as compared to the Dukler correlation. So, therefore, for any particular homogeneous mixture we find that the Beattie and Whalley's correlation is going to give you a consistently higher Mu effective and therefore, you find that in the 5 40 and in the 2 50 micro meter channel we find that for these 2 cases, there is a higher pressure loss due to mixing of the 2 phases.

In these 2 cases, the flow is predominately bubbly and flux and therefore, there is a higher pressure loss due to mixing of the 2 phases and the higher value of Mu effective, it gives us a or rather it enable facts to account for the increase inter facial shear in these 2 cases in the bubbly and the slug flow pattern. On the other hand if you observe these two micro channels in this particular case, the flow was predominately laminar here, the flow was predominately laminar and therefore, there was no need for a enhance Mu T P to account for inter facial shear. So, therefore, it is very important to remember that, under the same condition this gives a higher effective viscosity and therefore, when we need to, when there is an extra inter facial shear due to increase mixing and the inter phases.

Naturally this correlation gives us at better result, where as when the flow is more or less laminar and the inter facial shear is not very high.

(Refer Slide Time: 27:25)



A new variable defined

"Two phase multiplier"

$$\phi_g^2 = \frac{\left(\frac{dp}{dz}\right)_{TP}}{\left(\frac{dp}{dz}\right)_g} \qquad \phi_l^2 = \frac{\left(\frac{dp}{dz}\right)_{TP}}{\left(\frac{dp}{dz}\right)_l}$$

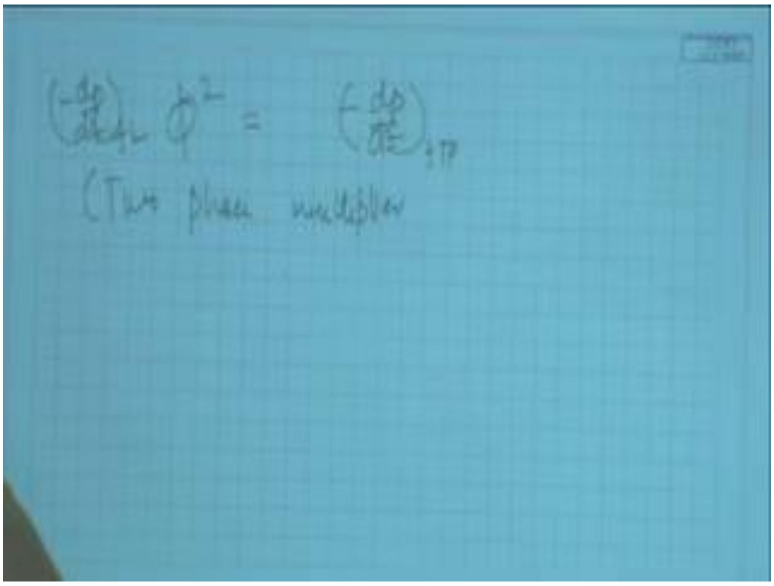
Such that $\Delta p_{fTP} = \Delta p_{fl}\phi_l^2$

Assuming entire mixture flowing as liquid $\Delta p_{fl} = 2 f_l \frac{L}{D}\frac{G^2}{\rho_l}$

A graphical relationship to obtain , as well as void fraction α from expressed as

$$X^2 = \frac{\phi_l^2}{\phi_g^2}$$

(Refer Slide Time: 27:28)



$\left(-\frac{dp}{dz}\right)_{fL}\phi^2 = \left(-\frac{dp}{dz}\right)_{fTP}$

(Two phase multiplier

Then in that case the Dukler's correlation is better, now other than finding out 2 suitable f T P, a very conventional technique of finding out the frictional pressure gradient can be obtained by defining a particular variable pi square which is known as the 2 phase multiplier. What does the 2 phase multiplier do? The 2 phase multiplier it finds out the 2 phase frictional pressure drop when it is multiplied with a single phase frictional pressure drop. So, therefore, what it does? It is basically a ratio of the 2 phase frictional pressure drop to the ratio of the single phase pressure drop of either have the phases flowing, alone in the micro channel.

So, in this particular case, finding out the single case pressure drop is not a very big deal. So, 1 this can be found out and we can find out and estimate of 2 phase multipliers from known into parameters. We can multiply the 2 and we can find out the frictional pressure drop during 2 phase homogeneous flow. So, in this particular case, we do not need the true phase friction factor and on the contrary, we can find out the 2 phase friction fact rather 2 phase frictional pressure drop by using a multiplier. So, therefore, we stop for now and we proceed to find out different relationships to estimate the 2 phase multipliers and predict the frictional pressure drop accordingly.

Thank you.