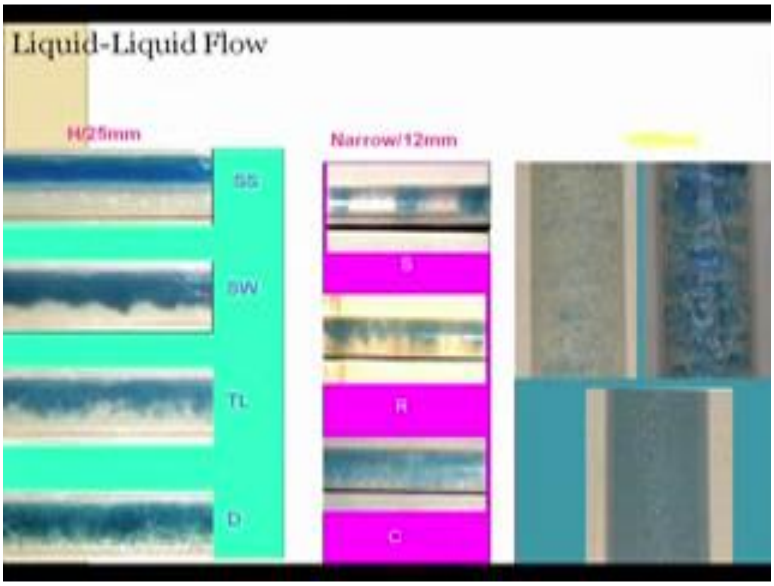
Adiabatic Two-Phase Flow and Flow Boiling in Microchannel
Prof. Gargi Das
Department of Chemical Engineering
Indian Institute of Technology, Kharagpur

Lecture No – 02
Brief Introduction to Multiphase Flow (Contd.)

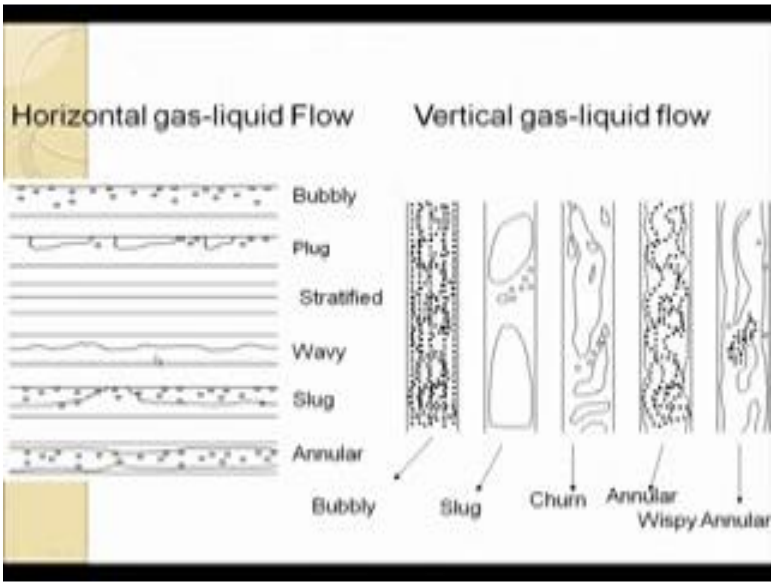
Well hello everybody, we continue with our discussions on the introduction on the multiphase flow. I had already discussed in my last lecture, I had already discussed the typical flow patterns which occur when, gas and liquid flows through a circular pipe or through any particular semantics, it can be rectangular pipe more or less the same flow patterns or a square pipe also the same flow patterns as should seen.

(Refer Slide Time: 00:29)



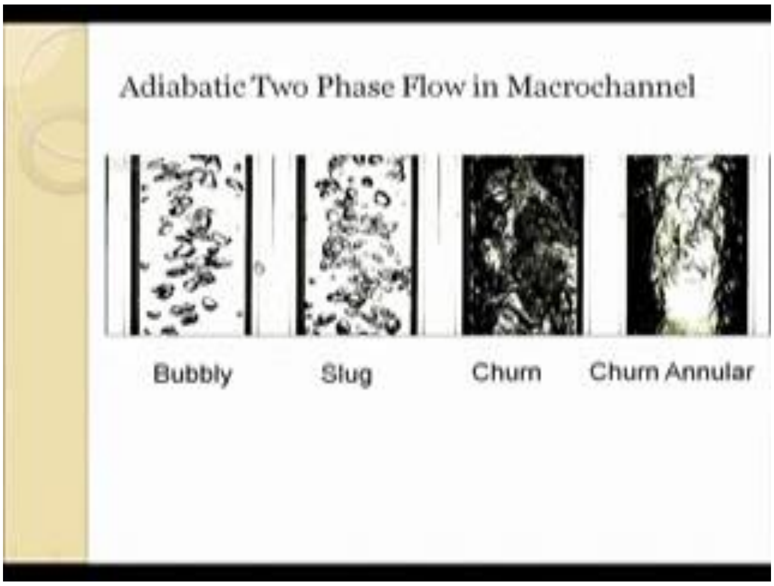
Now suppose instead of air water, I introduce may be an oil; it can be kerosene, it can be towline, it can be anything. I introduce another oil, do we expect the same flow patterns to exist? See one thing is for sure gravity, in this case also will be trying to pull the lighter phase towards the top, heavier phase towards the bottom.

(Refer Slide Time: 01:34)



Therefore, at low flow rates we have the satisfied smooth, and then as we increase the phase velocity, we have stratified waving, now if you remember in my last slide; in my last slide from here if, I increased the phase fluorides, we found that there was some points where the waviness of the interface was so much that, it was touching the upper wall, as a result of which plugs were formed and it resembled the slug flow pattern observed in vertical tubes; although it was an asymmetric slug flow.

(Refer Slide Time: 01:59)



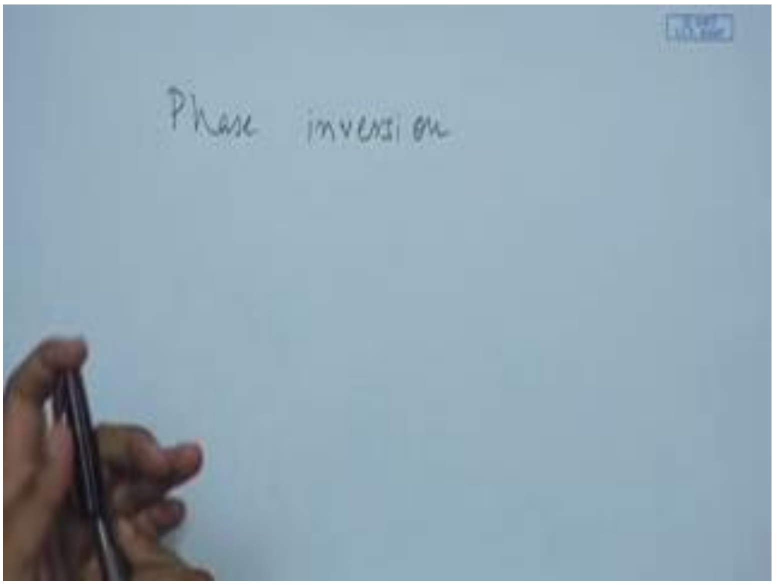
Now, this particular case if you find; we find that due to the highest surf extension of the liquid, it cannot assume the shape of the elongated plugs as we observed in gas liquid cases; on the contrary when the waviness is very much, then it shreds the interface.

And therefore there is a large amount of droplet of both the phases entrained at the interface between a continuously kerosene phase and a continuous water phase. This did not happen for horizontal air water flows, but in this case it happens because the liquid tend to remain spherical and they cannot sustain or they are not stable at an elongated shape.

Therefore, after stratified wavy instead of slat flow, we get a 3 layer flow pattern and as we increase the velocity; we find that 1 phase gets disposed into the other. Now here I have got a very important point to tell. While we were discussing gas liquid flows; repeatedly I had been telling you that, when there is less gas large amount of liquid we have bubbly; when we have large gas less amount of liquid, we do not have droplet we have annular; why because the liquid phase can wet the pipe wall, the gas phase cannot wet the pipe wall, but when we are having 2 liquids either of them can wet the pipe wall; it depends up on the hydrophobisity or the hydrophilisity of the pipe, like which phase will have a greater tendency to wet the pipe wall, but you must remember that either of them can wet the pipe wall.

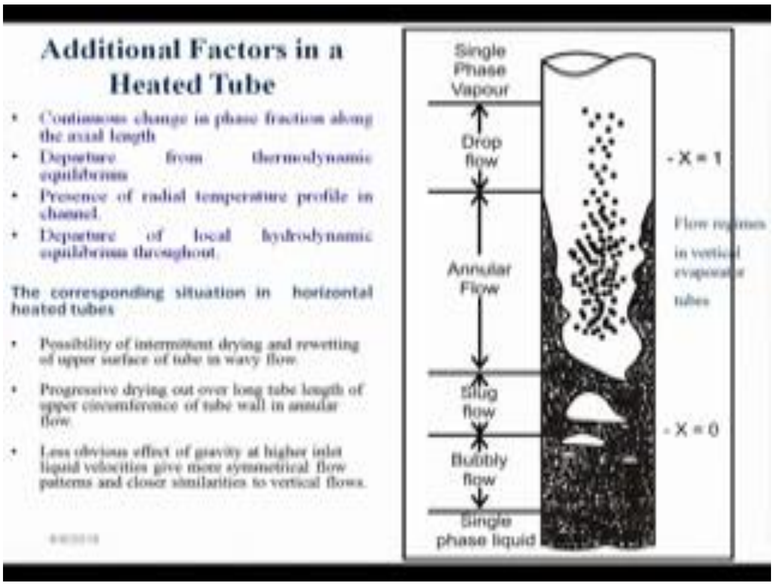
Therefore, just like we can have oil droplets in water, we can also have water droplets in oil. Therefore in a vertical pipe, what do you find; a pipe say of 1 inch diameter or 25 millimeters diameter, then the oil is in a smaller proportion compared to water; we have oil droplets dispersed in water. As we increase the oil velocity, the oil tends to take the several irregular shape, but if the pipe diameter is not very narrow, it never assumes the access symmetric bullet shape, which we observe for case of Taylor bubbles of fear; they take some irregular shape and finally, increase the oil velocity of more and more, a time comes when the oil becomes the continuous phase and water gets dispersed in it. Now this unique phenomena; which occurs for liquid - liquid cases, it does not occur for any other phase flow situation. And this particular phenomena of the continuous phase getting inverted to the dispersed phase and vice versa, this is known as phase inversion

(Refer Slide Time: 05:14)



During phase inversion we find that, 1 phase it tends to become continuous from dispersed and the other phase tends to get this from continuous and this unique phenomena of phase inversion, since it is concerned or rather since it is associated with the making and breaking of large number of inter phases, it is usually associated with the large amount of pressure drop and the high degree of turbulence or mixing, this was for adiabatic condition. Now suppose we go for a heated tube, where may be a single component say a liquid is being introduced and heat is being supplied from the walls and as it flows up; change of phase occurs, now what happens in this particular case? The tube is heated maybe say sub cooled water is coming in.

(Refer Slide Time: 05:44)



Initially we have single phase liquid in this particular case, then as the liquid starts getting heated; bubbles start forming. Bubbles will start at some nucleation at the wall, moment the bubbles start forming, it will remain attached for the wall for a very short time and then it starts getting detached and it rises due to buoyancy as well as due to flow of the liquid. Therefore, we get something like the bubbly flow pattern; now again as this particularly heated liquid or this particular 2 phase mixture, starts flowing up we find that more and more bubbles are formed; as more and more bubbles are formed, they get they come very close they start collision; moment they start callusing naturally the vapor bubbles they will assume their stable shape which is nothing but the access symmetric bullet shapes sort of a thing or the Taylor bubble sort of a thing.

Therefore, this slug flow sets in and then from slug flow as more and more amount of liquid gets vaporized. Large number of Taylor bubbles form, naturally they quails with one another and when they quails they form a continuous gas core and naturally they push the liquid to the side it forms a annular flow pattern. If heat is continued and the tube is long enough, what happens there is annular flow the liquid film which is being heated and the vapor core in the center region; now this liquid film it keeps on getting depleted due to 2 reasons, the first 1 is because of vaporization, some amount of liquid film gets vaporized into the vapor phase and Secondly, due to inter facial share which increases as more and more amount of vapor is formed, as the vapor velocity increases.

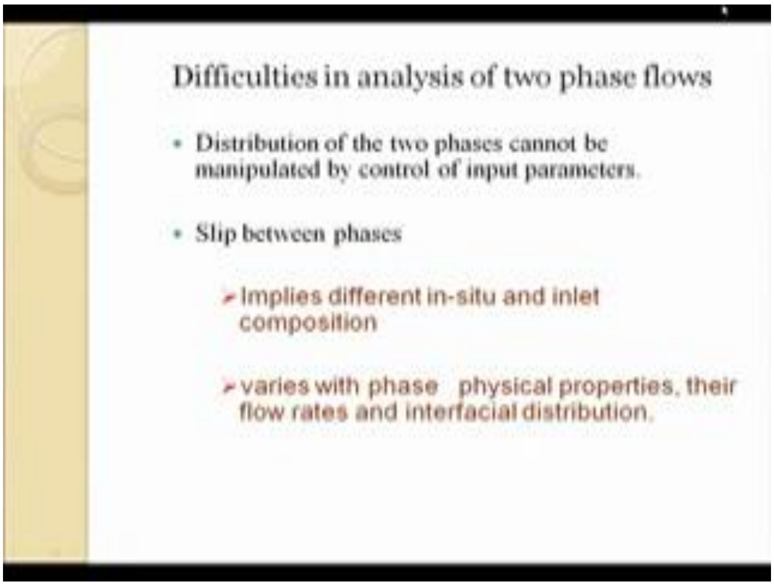
Therefore, this inter facial share also increases and it and the liquid from the film gets sheered as droplets here, possibly then after that, in a heated tube we get the droplet flow pattern, which we did not get for adiabatic cases and finally, when all the liquid has vaporized we get single phase vapor form.

Therefore, what we find, when we are dealing with the heated tube, then we find that there is departure from thermodynamic equilibrium also there is a radial temperature profile. Now due to these 2 reasons we find that, the flow pattern it changes inside the tube, which did not happen adiabatic case, if all the input parameters were kept constant.

Firstly, the other things which we find is, that in this particular case if you observe the flow patterns, there are 2 new things; one is joint flow which was very prevalent when we were discussing your vertical air water flows is not present here. The other thing is droplet flow comes into picture.

Now, this was the case of a vertical heated pipe. If simply make the pipe horizontal, keeping everything else constant and introduce water here, the factors which were there for a vertical pipe namely radial temperature profile departure from thermodynamic equilibrium; will persists along with that, asymmetry due to the gravitational affects sets in and the situation tends to get much more complex, with the possibility of intermittent drying and re wetting of the upper surface of the tube. In this way if we keep on proceeding, we find those more and more complex phenomena or more and more interesting phenomena; I should say, sets in as we deal with other combinations of 2 phase flow situation.

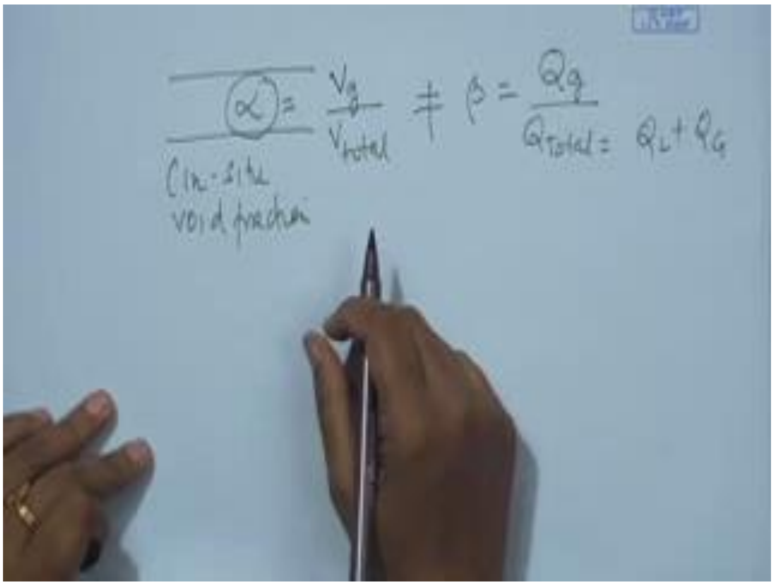
(Refer Slide Time: 10:15)



Therefore, from this you have understood that, what are the basic difficulties of analyzing 2 phase flow, the basic difficulties are 2. Number 1, The 2 phases can distribute themselves in a number of ways as you can see; that depends as I have already discussed, it depends up on the conduce geometry, the conduce inclination, the direction of flow phase physical properties and so on and this is not under the control of the experimenter or the designer, along with that what do you find that with the interaction of the 2 phases changing, the interfacial shred changes and we have to remember the most important thing that, the 2 phases have different densities; as a result the lighter phase tends to slip past the heavier phase.

Due to this, if you have introduced the 2 phases at a known composition, the same composition does not take place when the 2 phases are flowing inside the pipe; due to the existence of the slip. Or in other words, if we are talking about air water mixture, the insetive void fraction will not be equal to the inlet fraction of the 2 fluid or rather of the 2 fluids. Therefore, what it implies, the 1st thing that it implied is that, the 2 phases suppose for the time being we assume them to air and water.

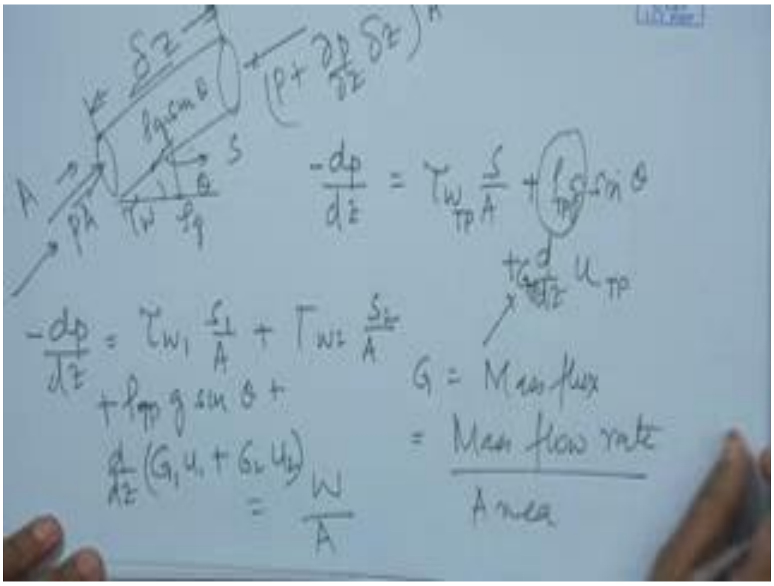
(Refer Slide Time: 11:58)



These 2 phases we find that while they are flowing; they have one particular void fraction say alpha inside the tube, how do we define this alpha; this is the say the proportion of the gas phase or rather the volume occupied by the gas phase divided by the total volume of the pipe and this will not be equal to the inlet volume fraction, which we define as beta. Therefore this is the insetive void fraction and this is the inlet void fraction or the inlet composition, this will depend upon the inlet flow dates if we denote Q with the flow rate, then this is going to be QG by Q total which is nothing but, where Q total is equal to QL plus QG. Now due to this, several problems arise

What are the problems suppose we would like to analyze this 2 phase flow situation, the analysis will be just the same as the single phase flow of any particular fluid, through a pipe. Now if we go for a single phase flow, say let us develop the momentum equation, I will be not be going into the details of this.

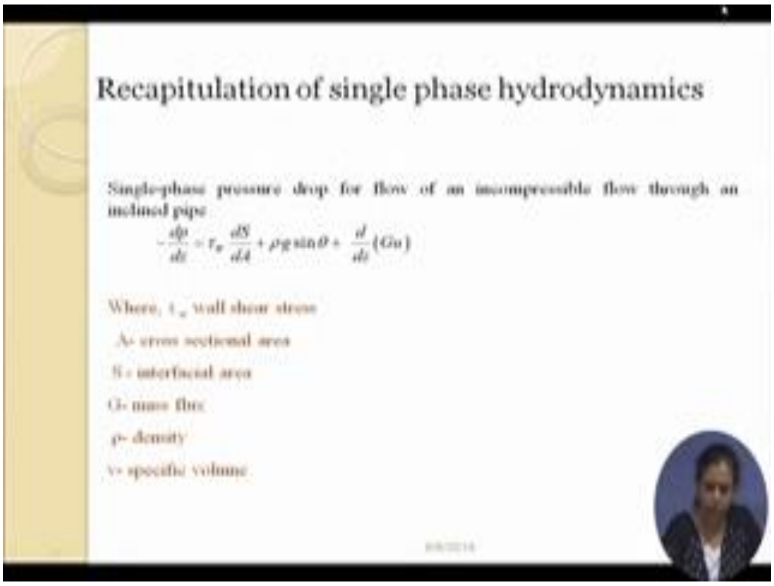
(Refer Slide Time: 13:25)



Suppose we are having may be say we consider delta z portion or delta z length of the pipe of cross sectional area A and here we find and may be the wetted perimeter as S. In this particular case, the pressure is going to or the pressure force is PA and in this particular case, we find that, the pressure force is P del P del Z into delta Z into A and here we find that the gravity is acting and there is a component in this particular direction.

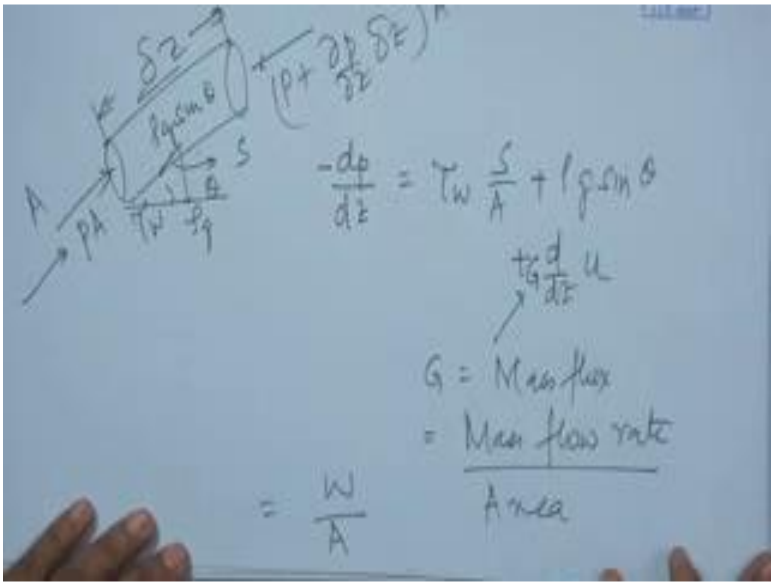
If this is row G, the component of gravity will be row G sign theta, and since flow is occurring in this particular direction there will be inter facial share. If we consider these the forces which are acting on this particular feed element, namely the pressure force, the body force and the wall force wall share is given by TW and if we equate it with the rate of change of momentum.

(Refer Slide Time: 14:36)



Then what do we get, we get a pressure drop relationships. I leave it as a home assignment, to perform this particular balance and then finally, arrive at an expression to find out the pressure gradient. This expression is TW the S by A plus say row G pipe inclined, then have a sign theta component; where theta is the angle where horizontal plus this gives you d d z of u into say G.

(Refer Slide Time: 15:35)

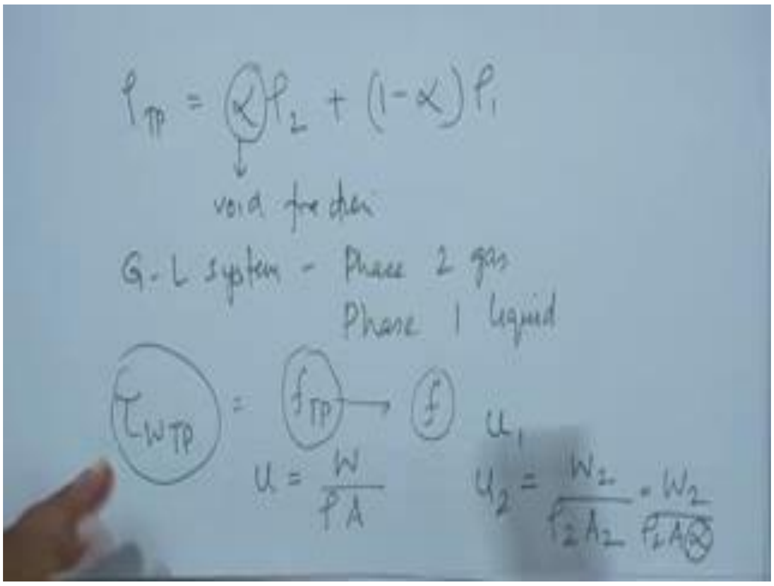


G is the or rather I will put is as W by A where G is the mass flask, which is equal to the mass flow rate divided by area in other words W by A in my set of this, was for single phase flow. Now suppose instead of single fluid say for example, 2 fluids are flowing here. What do we find for this particular case, what are the things let there be any sort of distribution here. What happens is this 2 fluids no matter in whatever they are mixed, they will be interacting with the wall.

Therefore, this is going to become TW 2 phase, some sort of interaction with all and instead of single density it is going to be a mixture density and this U is going to be mixture, rather mixture velocity. If the 2 phases are completely mixed, then this equation is fine we have a GTP here as well and if they are they are separate, then in that case the equation what it should become they should be TW1 S1 by A plus TW2 S2 by A plus row TP G sign theta plus d d z of say one fluid is G1, one fluid is denoted by 1 the other is 2 we get something of this kind.

Now, when we try to evaluate the pressure of using either of them, what do we find first thing we do not know is row TP.

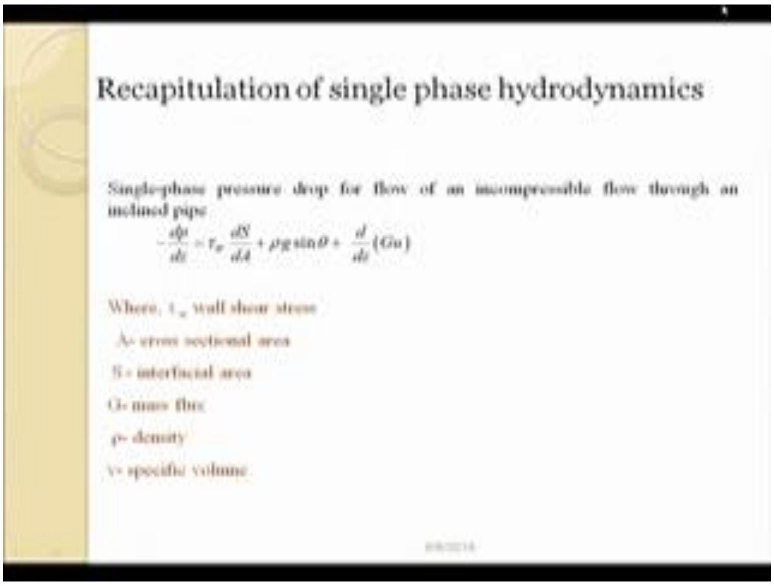
(Refer Slide Time: 17:22)



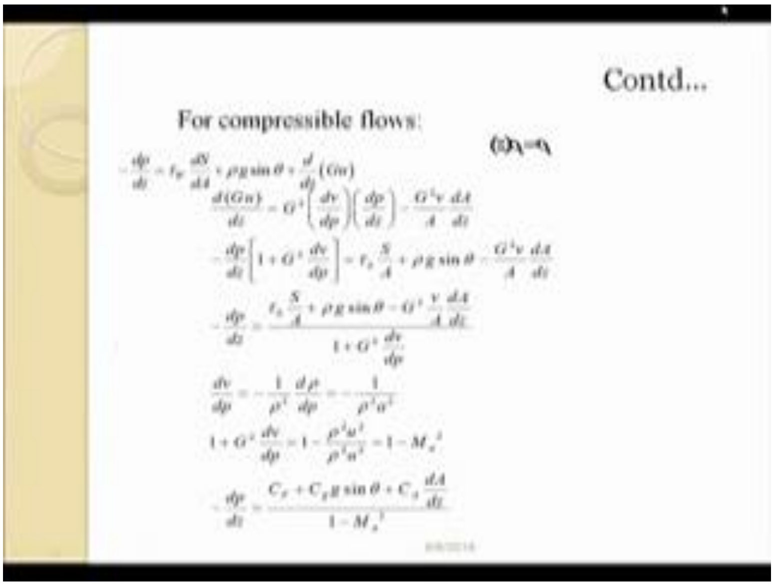
On what does row TP depends, it depends upon incite void fraction mind it; it depends upon incite and not on the inlet void fraction. Inlet void fraction is a known fraction, but incite void fraction we do not know. And row TP it is a function it can be expressed as, if alpha is the void fraction and say for a gas liquid system, my phase 2 is gas, phase one is liquid, then what do I get row TP should be equal to alpha row 2 plus 1 minus alpha row 1. For finding out the gravitational pressure drop, you need to know alpha and alpha is no way related in a straight forward fashion with theta; this is the first problem we face.

What is the next problem we face, how is Tw TP related or how can it be evaluated; can be defined something like 2 phase friction factor, then in that case how is this 2 phase friction factor related with a single phase friction factor which we have. This is also very much not known to us, the other thing is if you are defining UTP say. So, this u it is function of say mass flow rate density and area right. So, therefore for single phase flow it is related in this particular way, if we are having 2 phases, 2 phases having different velocity and they are in no way related to the velocity that the inlet, say 1 fluid has the velocity U1other has the velocity U2. So, therefore, what is U2 it is W2, the mass flow rate it is definitely measurable row 2 by A2, where A2, is nothing, but it can be written down as, A into alpha the void fraction. Therefore, in order to find out how your U2 is varying with length, you need to find out alpha. Therefore, we find if alpha cannot be determined from input parameter, which it cannot do. It acts to the additional complexity of 2 phase flow.

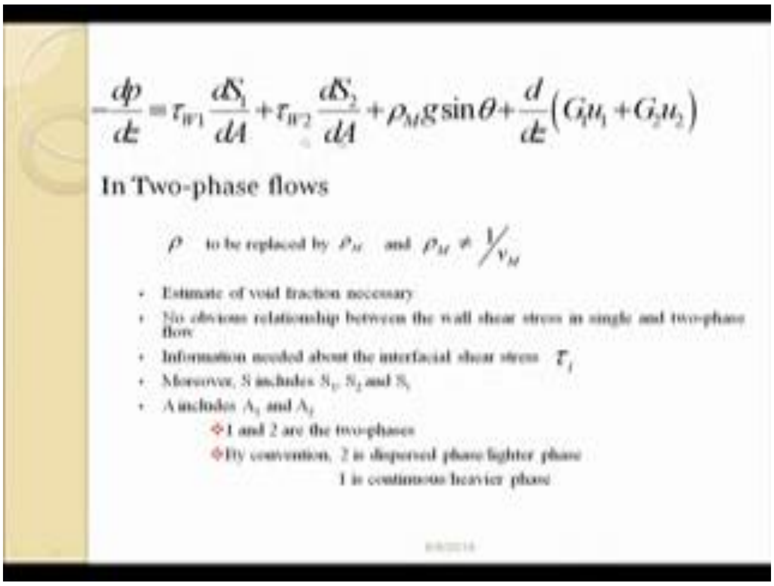
(Refer Slide Time: 20:05)



(Refer Slide Time: 20:07)



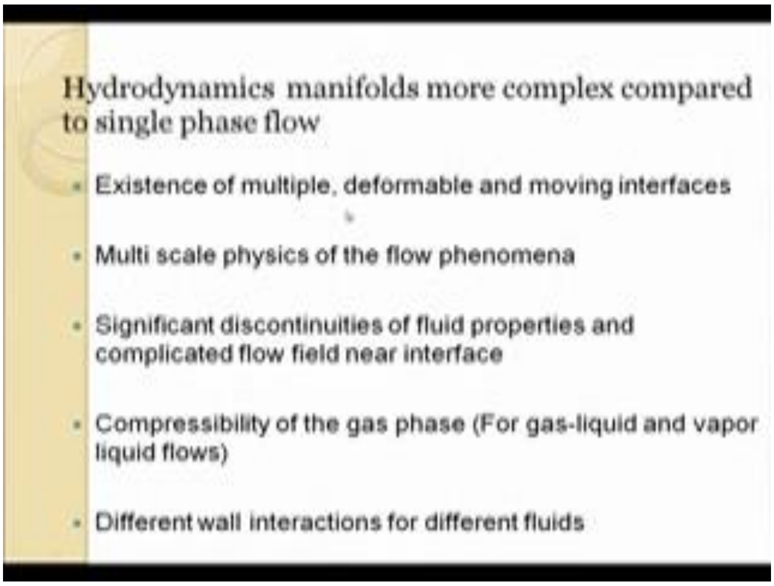
(Refer Slide Time: 20:09)



Just the way I was discussing till now. Therefore, if you can write it in this particular way we find that row has to be written down or it has to be substituted with row TP here of course, I have defined as row M the mixture velocity, you can do whatever you wish and we find that it is essential to have an estimation of void fraction as I have already said; there is no obvious relationship between wall shear in single and 2 phase flows, we also find that S it includes S1, the wetted perimeter for phase 1, S2 the wetted perimeter for phase 2 and apart from S1 S2 there is also an inter facial area where the 2 phases interact.

Therefore, we find even for finding out the simple pressure drop also, it becomes difficult why number 1, the 2 phase can distribute in a large number of ways and unless we know the distribution, we cannot find out TW1, TW2 we cannot find out S1 S2 and again depending upon the distribution, the void fraction is going to be decided and unless we know the void fraction we cannot find row TP or row M. Therefore, this suggests why the 2 phase flow becomes much more difficult as compared to single phase flows.

(Refer Slide Time: 21:43)

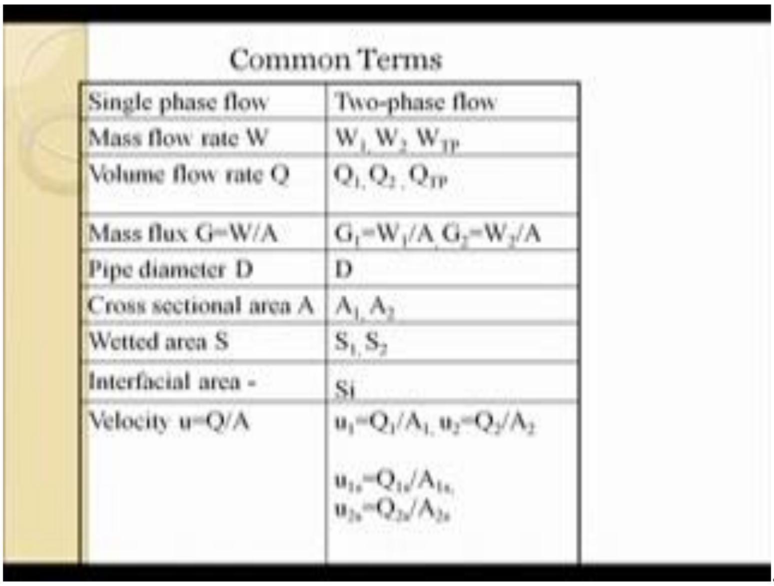


The reasons primarily being; there is an existence of multiple deformable and moving interfaces, there is multi scale physics of the flow phenomena, this significant discontinuities of the fluid properties and complicated flow field near the interface, you can very well understand that near the interface you suddenly shift from liquid properties to the gas properties, in addition when we have 1 phase that is the gas phase for example, for gas liquid flows, vapor liquid flows or gas solid flows the compulcibility of the gas phase also comes into picture and definitely there can be different wall interactions for the different fluids.

Therefore, we find that, when there is one phase present and we just introduce the second phase the situation becomes much more complex because the 2 phases interact not only with the wall, but also among themselves accordingly they distribute in a wide variety of ways and since the 2 phases have different density, the lighter phase tends to slip past the heavier phase as a result of which the incitive void fraction is different from the inlet composition; inlet composition we can manipulate, but incitive composition there is no straight forward way of finding out the incitive composition, again this incitive composition depends upon the distribution; definitely if you have some or a if you have devised some particular way of finding alpha in bubbly flow you cannot use the same relation you cannot use the same relation to find alpha for annular flow or if you have some particular relationship to find alpha for gas liquid fluid bubbly flow, there is no guarantee that the same relationship can be applied for oil and water disposed flow.

Therefore, with these things I think we have got clearly good introduction of multi phase flow, but before I start I would just like to show you I would just like to discuss in very brief the terms which we will be coming across frequently.

(Refer Slide Time: 24:15)

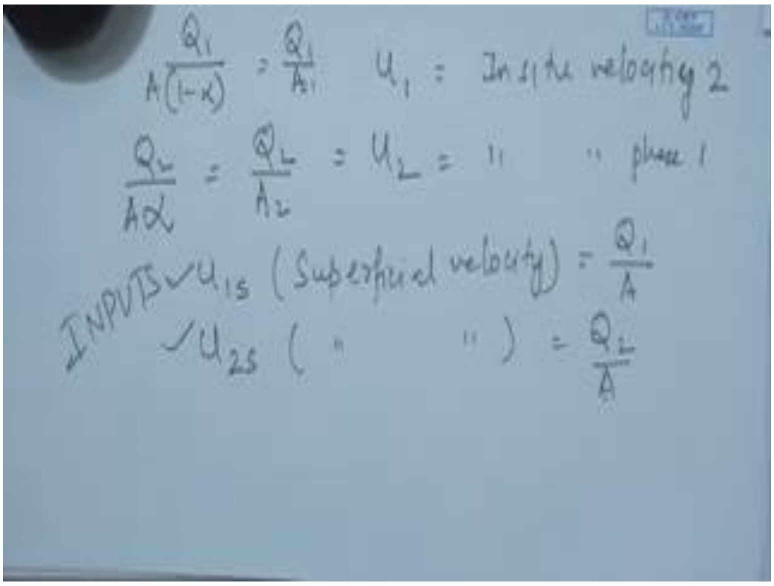

Common Terms

Single phase flow	Two-phase flow
Mass flow rate W	W_1, W_2, W_{TP}
Volume flow rate Q	Q_1, Q_2, Q_{TP}
Mass flux G=W/A	$G_1=W_1/A$ $G_2=W_2/A$
Pipe diameter D	D
Cross sectional area A	A_1, A_2
Wetted area S	S_1, S_2
Interfacial area -	Si
Velocity u=Q/A	$u_1=Q_1/A_1$, $u_2=Q_2/A_2$ $u_{1s}=Q_{1s}/A_{1s}$, $u_{2s}=Q_{2s}/A_{2s}$

My reason for discussing these terms are, see you have come across these terms, but may be not the same nomenclature. If all of us use the same nomenclature or in other words suppose if I have a unified nomenclature, then at every point I do not need to define those things for example, as far as I am concerned, for me the mass flow rate will be denoted with w. Now let me clarify one this at this point, you are free to use any other nomenclature, but in that case you have to define your nomenclature. Normally as chemical engineers or mechanical engineers, we define mass flow rate as M dot, but for this class, I prefer to keep it as W volume flow rate as Q there is one particular term we do not come across much when we are discussing single phase flows, but will be coming across wide frequently into phase flows, that is the mass flux. Just like heat flux, mass flux, it is the mass flow rate per unit area, pipe diameter D cross sectional area A, wetted perimeter S, these are all fine de equip corresponding terms in 2 phase flow are naturally we have got 2 phases.

There are 2 w and a total w we have two Q and a total Q, we have 2 mass fluxes and definitely a total mass flux also, along with the cross sectional area we need to know the area occupied by phase 1 and phase 2. We need to know the wetted perimeter which is rather the perimeter, which is off the valve, which is contact with phase one, S1 which is in contact with phase two, S2 and of course, there is an inter facial area as well. As a consequence what do we find, we find that there are 4 velocity terms instead of 2.

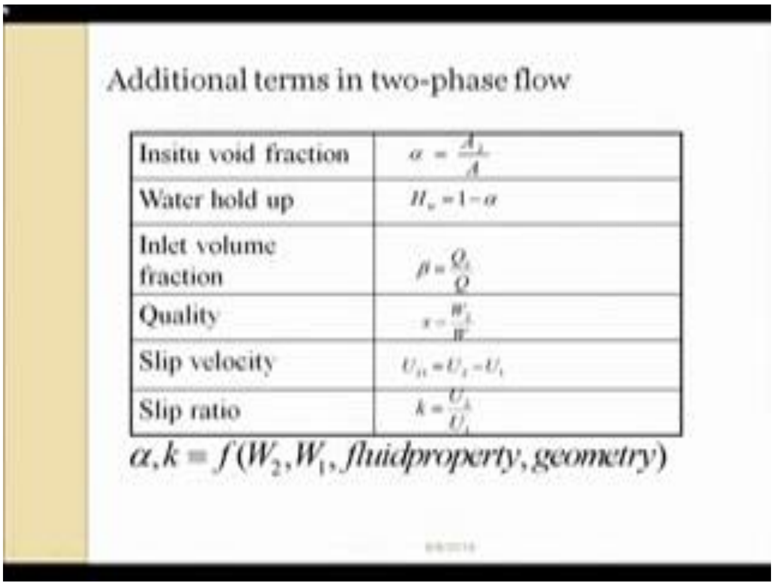
(Refer Slide Time: 26:31)



Because U1 U2 they are the local or the incite velocity. So, therefore incite velocity of phase 2 and this is the incite velocity of phase 1. By definition U2 should be equal to Q2 A2 this should be Q1 by A1. Now what now what are this A1, A2 they are the cross sectional areas occupied by phase 2, cross sectional areas occupied by phase1. Naturally this can be defined in this particular way, this can be defined in where alpha is the void fraction or fraction of phase 2. Therefore along with these 2, just because we refer to velocity of the fluids very frequently, therefore, what we will prefer to do will also prefer to define 2 other velocities, which are known as the superficial velocity where this is the velocity which the fluid will have, if it were flowing alone in the pipe.

Therefore, these are measurable parameters, they are just your volumetric flow rates divided by the cross sectional area because they define the velocities which would have, if they were flowing alone in the pipes. Therefore these are inputs while U1and U2 is outputs. Therefore just I have mentioned.

(Refer Slide Time: 28:14)



The additional terms are definitely incitive void fraction, the inlet volume fractions and the other important thing which I forgot to tell you is the quality; which is the weight fraction of these 2 in the flowing mixture this x varies in a heated tube and it is a constant for an adiabatic condition.

Right now before I end I would also like to specify one particular thing that, by convention might lighter phase or the dispersed phase I denote it as phase 2 and all the properties including void fraction, inlet volume fraction, quality we define with respect to this phase; that means, for an air water flow, my air is phase 2, and water is phase 1. for kerosene, water flow may be if kerosene is in a smaller proportion or it is the discontinuous phase kerosene will be phase 2 and water will be phase 1. And most of the properties we define in terms of phase 2.

Therefore, with I complete my particular introduction of multi phase flow and in the next lecture I will be discussing the rather these uniqueness or the specialties it is not the uniqueness exactly the specialties of 2 phase flow through miniaturized systems.

Thank you very much.