Adiabatic Two-Phase Flow and Flow Boiling in Microchannel

Prof. Gargi Das
Department of Chemical Engineering
Indian Institute of Technology, Kharagpur

Lecture -18
Void Fraction and Pressure Drop in Reduced Dimensions – Experimental Results (Contd.)

Hello everybody. We continue with our discussions on pressure drop measurements as I had mentioned that, there is very the scarcity of data in the pressure drop measurements and there are several uncertainties and challenges related to with the measurements. We find in this particular case as I had repeated. Usually the tapings are done between the inlet and the outlet planer. Naturally the pressure drop, it includes the entry and exit losses, it includes the losses, the expansion and contraction losses.

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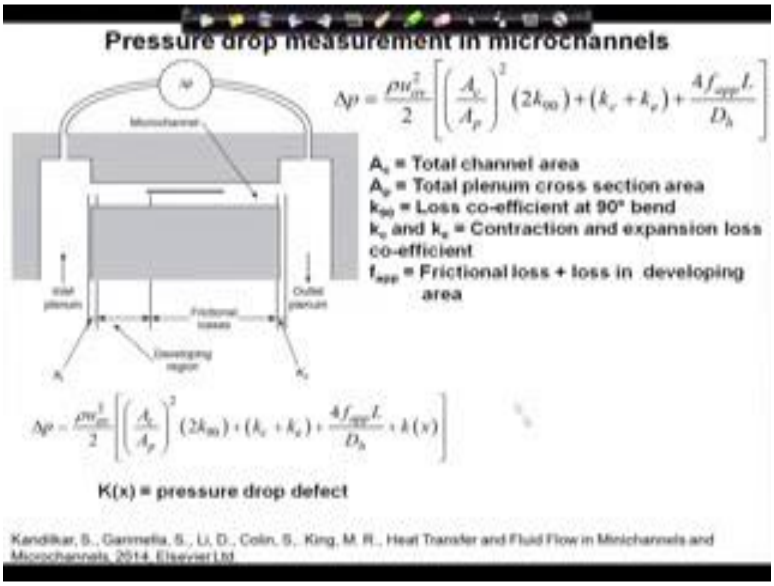

And there is also a loss due to be the loss co efficient at 90 degree bends. So, all of these are included in the measurement that we get, and eliminating these losses from the measure pressure drop is definitely quite a challenge.

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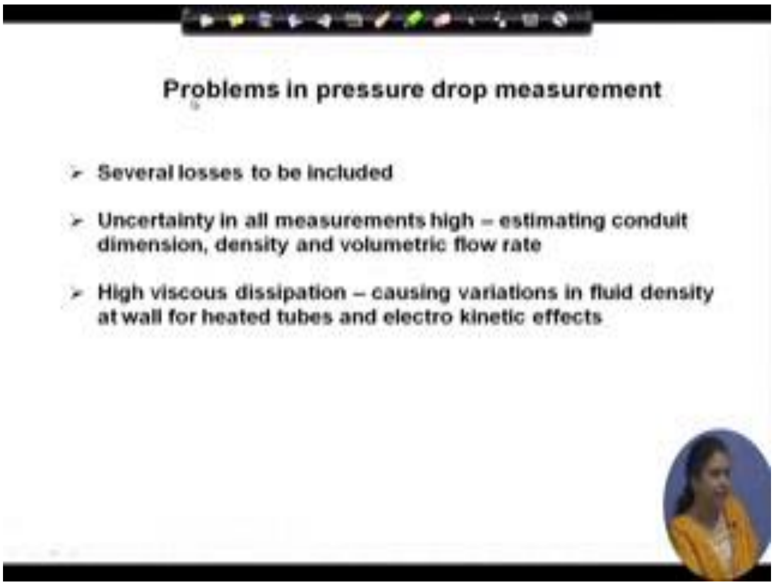

Therefore, the first thing as I have told you several losses have to be included. The other thing is whenever you have any measurement, anywhere. There are several uncertainties associated with that particular measurement. And then this case if you realize, the uncertainties starts from the measurement of the conduit diameter. The micro challenge dimension is in the range of micros and we are very well appreciate that measuring such a small dimension, it requires how much level of precision it requires and how difficult it is to have an accurate measurement number one.

How difficult it is to maintain a uniform micro channel, without any particular roughness or uniform roughness. Therefore, there are lots of uncertainties involved in the measurement of channel dimension. The volumetric flow rates, they are very less. The volume of fluid held up here, these are also very less. Naturally, in this particular case, measurement of volume, measurement of the other parameters, there are several uncertainties which have to be accounted for and so naturally all these multiplied gives you a large uncertainty, in the measured value of pressure drop that you get.

And finally there is also one more thing which we should consider. Particularly with respect to boiling two phase flow, there is a high viscous dissipation as the viscous forces are more important as compact to initial process. Therefore, there is a high viscous dissipation, which causes variations in fluid density at the wall for heated tubes and also there are some electro kinetic effects as well and these things they also contribute to the pressure drop measurements, but it is very difficult to account for these particular measurements.

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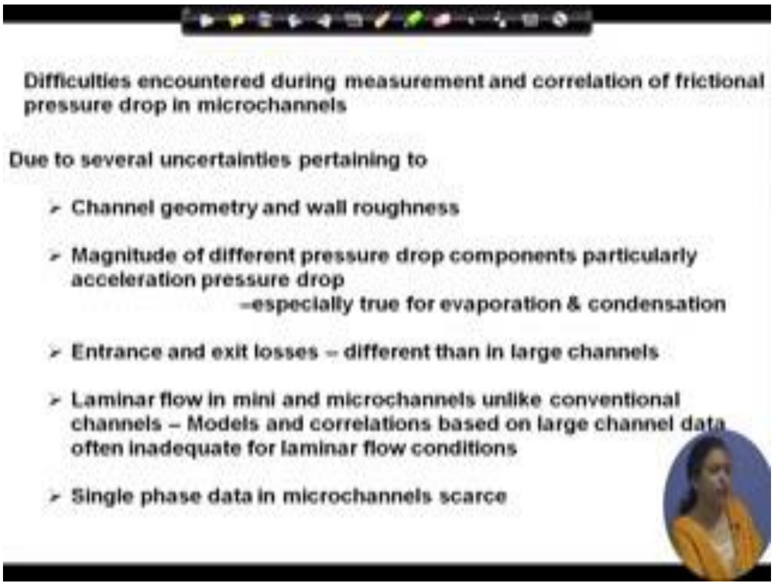

Now, such things are also there for macro channels, but in those particular cases the frictional pressure drop is not always as important as the case of micro channels.

Now, what are the other uncertainties which pertaining to micro channels? First thing is considering the thing which I had mentioned in the beginning, that in this particular case, the important pressure drop components are frictional and acceleration.

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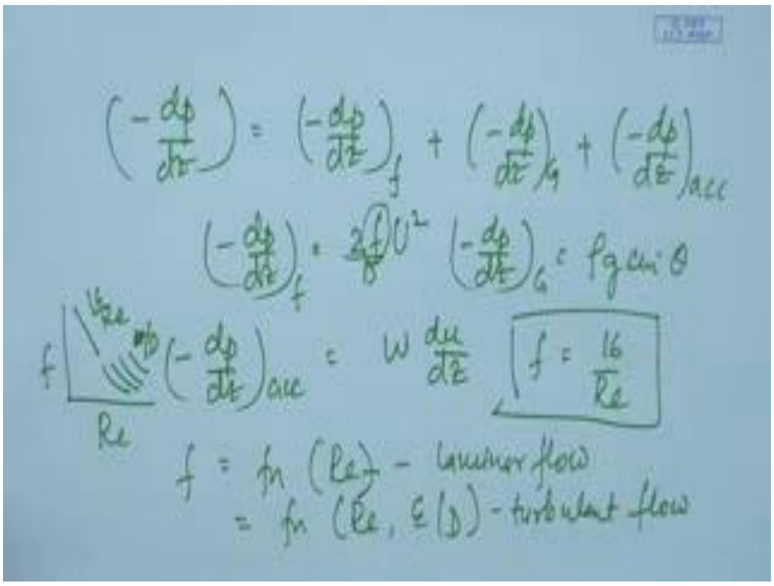

If you remember in the introductory class, I had mentioned the pressure gradient. It can be expressed as summation of 3 components. It is the frictional component. There is a gravitational component and there is a acceleration component as well, where this frictional component it can be written down as in the form of friction factor 2f by D U square, and the gravitational component, it can be written down as Rho G Sin Theta, where Theta is the angle of information of pipe with respect to the horizontal and the acceleration pressure gradient, it is naturally it was equal to your mass flow rate into the velocity gradient. Now, this is the frictional pressure gradient.

Now, in this particular case, what do we find? We find that the frictional pressure gradient, this was for single phase flow and for single phase flow we found that this frictional pressure gradient was expressed in terms of a friction factor, where it is well established for single phase flows that it is a function of Reynolds number for laminar flow and it is very well set that it is very well established that, it is a function of usually a function of Reynolds numbers and draftiness factors for turbulent flow.

If you remember the moody plot you will be recalling that the plot which is f verses R E, it has one single curve, corresponding to 16 by R E for the laminar regent and the large number of curves corresponding to different epsilon by D values in the turbulent flow regent. Now here I would like to mention the uncertainties if we take them one by one, we find that since friction pressure gradient is important and f it depends upon a rather the shear, It depends upon the channel geometry and wall draftiness. Therefore, there is a large uncertainty associated with this.

The other thing is, if you remember that, or if you look at the graph which I have drawn, if we find that, for micro channels, mostly the flow is in laminar flow regent. Therefore, it is quite expected that life should much simpler because in this particular case, the relation f by equals to 16 by R E should be applicable. But at the same time we have seen, how much wall wettability and wall roughness affect both, the flow patterns as well as the void fraction, and other hydrodynamic parameters in micro channels. What does it signify? It signifies that, although flow is laminar in this case, wall affects are much more important. And our conventional macro channel information on single phase flow does not show such a trend. Therefore, this should be taken into account.

The other thing is, to find out the magnitude of the different pressure drop compliments. Usually when we measure the pressure drop as I have shown, it gives you a measure of the total pressure gradient or the total pressure drop, over a measured length of the test quantity. Now this as I have told you, it comprises of frictional, gravitational and acceleration pressure gradient. Now this acceleration pressure gradient, that arises why? In single phase flow, it use to arise only when there was a change in cross section of flow either when we encounter an (Refer Time: 07:42) or an expansion or a contraction, be it (Refer Time: 07:45) or not. It can arise, if we encounter some pipe fittings on the way. But other than that, in single phase flow, normally acceleration pressure drop is not encountered. It is encountered when the fluid, which is flowing, undergoes a change of phase. Suppose it is a liquid which is changing into vapor phase. Quite naturally movement the (Refer Time: 08:09) vapor phase is formed, because it has a lower density, it will try to flow faster to the conduit. And therefore, there is a change of momentum with a change in velocity of the liquid particles, which are vaporized to the vapor phase. And we find that, along with that in micro channels, even for adiabatic flow situations usually, as I have already mentioned several times, pressure drop is quite significant in this particular case, when the pressure drop is very significant, then naturally the gas phase, particularly the compressible phase, it has a tendency to accelerate as it flows through the conduit. Therefore, acceleration pressure drop becomes more and more important as we minimize the conduit size, even under adiabatic flow conditions and naturally it is much more important when there is flow boiling associated with it.

And finding out this particular special de component due to special acceleration is particularly quite or this is a factor. Now was this not a case for macro channel situations? Yeah, in those particular cases also finding out the magnitude of the different pressure drop components, mostly important and several studies have been performed in order to find this out. There are, for this particular studies, usually we need some sort of a relationships for slip ratio or some sort of a void quality relationship, on other words we need a model with some phase slip closer relationships. If we find out the void quality relation in this particular case, again if we start from the nomenclature part, what do we find?

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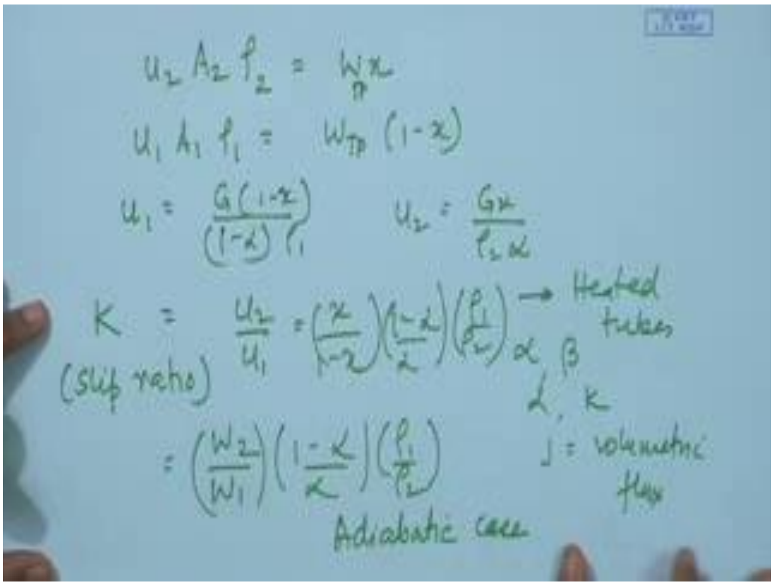

We find that, from equation of continuity, U 2, A 2, Rho 2, what is this equal to? This is nothing, but equals to your W the total mass flow rate into the mass quality. Similarly U 1, A 1, Rho 1, this is nothing, but equal to W T P into 1 minus X.

From here we get, U 1 should be equal to G into 1 minus X by 1 minus Alpha into Rho 1. U 2 should be equal to, similarly G X by Rho 2 Alpha.

What I would request you is that, before we start the analysis part, it will be good, if you go through the nomenclature section once more and try to establish the relationships between the different parameters, that we have established for example, analytical or rather the relationships between Alpha Beta, Alpha K, the concept of volumetric flux, which will be very important for a drift flux model and so on. If you are quite conversant with these things, it will be easier for you to understand the analytical models, which we will be dealing. So, from these what do we get? Suppose we try to define the slip ratio K, which is nothing but equal to U 2 by U 1, what do we find here? We find that, this is equal to ratio of these 2 X by 1 minus X 1 minus Alpha by Alpha into Rho 1 by Rho 2. This is the situation for heated tubes, where we have boiling two phase flow.

And it is better represented instead of X by 1 minus X, its better represented as W 2 by W 1 for adiabatic cases. Because in this W 2 and W 1, whatever is introduced, that remains as it is. So, therefore, this is the relationships which are used for adiabatic cases.

This is the relationship in terms quality, which keeps on changing as the fluid moves up, for the case of heated tubes. Now, in order to find out the exact functional form of this relationship, lots of experiments have been performed, but most of these experiments have been performed in macro channels, and there is no guarantee to tell, that the same relationships can be extended for micro channels. So, lot of additional investigations are required and often it can be said, that whatever relationships have been established for macro channels, do not or cannot be used for the micro channel flow.

But since in the absence of additional information, mostly we use them and they introduced a amount of error. Then naturally the other thing which comes into being as I have already discussed, it is the entrance and exit losses. Quite a number of good amounts of work has been done on entrance and exist losses on single phase flow through macro channels. It is well established. Two phase flow through macro channels also, some amount of good amount of work has been done and in micro channels the work is very scanned; very few 1 or 2 research papers have been reported on two phase, on the effect of abrupt expansion contraction and some such type of things in micro channels and they have defiantly shown that, the hydrodynamics is different in micro as compare to macro channels. Therefore, it is the using conventional correlations to predict entrance and exit losses in micro channels are not accurate. But this is what we are we are doing in the absence of further information and this also gives us much more additional errors.

And the other thing which I have already mentioned that, usually in this particular case there is a laminar flow, but the correlations in the models, which are based on large channel data, they are often inadequate for laminar flow conditions. As I have already mentioned, because in conventional systems in practical situations we hardly come across laminar flow conditions.

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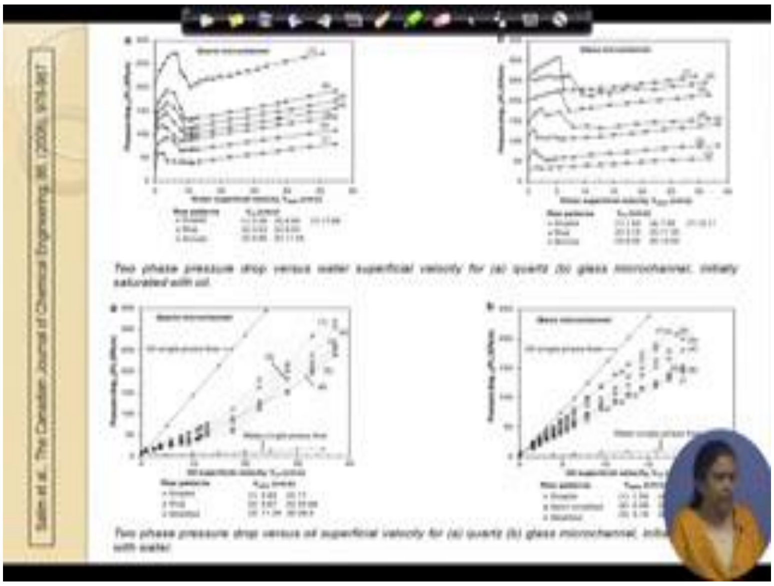

Now, we go for this, we will be very briefly discussing some pressure drop experimental results and which have been reported in literature.

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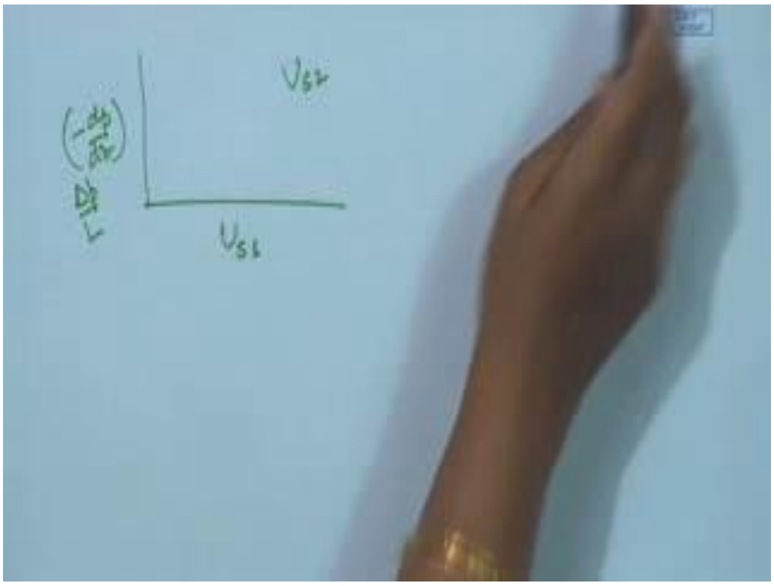

Now in this case, again just like I had mentioned in void fraction, we find that the results, the pressure gradient results, they are represented either as minus dp dz or Delta P by L, as a function of one particular superficial velocity, where the other superficial velocity as the parameter.

Now, usually what we do? We take up the continuous phase velocity or the disperse phase velocity is the axis and the other velocity as the parameter and this is the conventional way of depicting the pressure drop variation with input parameters. Now several graphs have been generated for gas liquid flows. I will be not going into the details of all those graphs, I will just try to describe one particular set of results, which were used for oil - water flows. I have already discussed the flow patterns, corresponding to the pressure drop results, which I will be discussing now.

And if you recollect or if you can go back to the slides, which have been reported by (Refer Time: 15:56) you will find that, there was a significant influence of the tube material. They had used 2 materials, if you remember, quartz and glass and there was also a significant influence, on which phase was initially saturating the conduit. We found that, there were significant differences, when we were working with glass and quartz micro channels and there was also a significant difference for wall wet sorry oil wetted and water wetted cases. This second part is not usually available for air water data and this is the reason, why I have selected oil water data for discussing the pressure drop results.

Now, in the pressure drop case you find that, it hardly matters whether we are working with the quartz or the glass micro channel, or in other words we can see that the conduit material has got a comparatively lesser influence on pressure drop. On the other hand, the saturation phases, whether it is initially saturated with oil or, whether it is initially saturated with water that has got a much more significant influence. Now what do we observe in this case? We observe that initially when it is saturated with oil, for both quartz and classic micro channels, we find that initially for very low values of water superficial velocity, the pressure gradient increases with increase of water velocity. Have a expected results, and after some particular critical water velocity which, usually is less than 10 centimeters per seconds, we find that, at the pressure gradient, it actually falls instead of rising, as we increase the water velocity.

But this particular decrease in gradient with increase in water velocity, it continues till a critical velocity of which, usually lies around or rather between 3 to 10 centimeters per second. This trend continues and henceforth, we find that the pressure gradient, it continues to increase with water velocity as expected. It happens for both the case for both the micro channels that has been used. On the contrary, if and the same experiments are performed, in the same micro channels with a same fluid pair, we find that if the channels are initially saturated with water, instead of oil, the flow pattern, the pressure drop trend changes completely. In this particular case, we find that the pressure drop, it keeps on increasing with oil velocity. They have plotted in both the cases; I find that they have plotted with a disperse phase as the X axis. So, it keeps on increasing and the increase is initially linear and then particularly for the quartz micro channel, it becomes much steeper as compare to linear.

Now, the reason for showing you this was not just to show you the trends, but also to enable us to think about the phenomenal and to find out whether there is a particular reason for this particular trend. Now before we start analyzing, I would like to tell you, that an identical situation was observed by several researchers during oil water flow in large diameter conduits, and what they set for this? There were number of things which were proposed. The first thing was that usually for very low water and higher oil velocities, there is a tendency of formation of core annular flow, which I have already discussed. It is when oil flows as a central core and there is a thin water film, annular film fits around the oil core and it separates the oil from the wall. Moment the core annular flow patterns is formed, we find there is a drastic reduction in pressure drop, because in this the wall shear arises, just because of the contact of water with the oil.

But, other than that also people have reported that, even if core annular flow is not formed for high oil and low water velocities, when water is disposed as droplet in the oil also, pressure drop decreases. Why? Oil always has a higher viscosity compared to water. So, naturally when there is water in an oil emulsion, the effective viscosity is much a less as compared to the viscosity of oil only, when flowing through the pipe. So, as a reduction of the effective viscosity, the frictional pressure drop falls down. This has been reported earlier and we also believe, by observing or recollecting the flow patterns we had discussed, that mostly this particular region it was, it exhibited droplet flow and slug flow.

Or in other words, droplet and elongated droplet flows. And therefore, this reduction, it is attributed to the reduction in effective viscosity of the two phase mixture, as compare to the viscosity of only oil, which was flowing initially in the pipe and then naturally after a time, the pressure drop increases because the superficial velocity increases. Such a situation does not arise in this case because when we introduce oil in water, the effective viscosity rather goes up, it does not comes down. So, therefore, there is a study increase in this particular case.

Now here I would also like to mention that, very interestingly it is not only that, this particular trend is observed for a oil water flow in large diameter pipes, but several researches have also reported such a phenomena for air water flows in micro channels, particularly during in horizontal as well as in the vertical micro channels, particularly during slug flow and also in horizontal channels during slug annular transition. And for this particular case, the reason for this drop was thought about or was attributed something of this sort. What happens when a plug flow occurs?

There is a liquid fill which separates the gas plugs or the oil plugs from the oil sorry from the wall. Now this flows in a counter current direction to the rise of plugs and at the end of the plug, it comes and meets with the upward flowing or it comes and meets counter currently the water slug, which is just following the oil plug or gas plug. Now moment they come and meet, in this particular case, there is a large shear associated and due to the expansion of the liquid film from the film regent to that liquid slug regent, there is a pressure drop involved.

And due to this particular pressure drop, people have found out that such a trend of pressure reduction with increase in water velocities is also observed for air water cases. So, all this factors combined, may be the reduction in effective viscosity as well as the expansion of the water film, sorry the expansion of the oil film, as it flows along waters plugs and then comes and meets the oil plugs below the water plug, possibly this particular reduction occurs. So, therefore, this more or less gives an idea regarding the trend of gas liquid and liquid - liquid pressure drop variation, with fluid properties and pipe diameters in oil water and air water cases.

So with this, I believe we have more or less completed the discussions on the thermo dynamic rather the discussions on the experimental results of void fraction and pressure drop reduce dimensions and we would now shift over to the theoretical analysis. We have seen that well, the void fraction exhibits some trends special drop, they exhibits some trends. Now how are these particular trends, they are how can these be analyzed and how can they be correlated. So, that without doing experiments, we will been a position to predict the hydrodynamics of flow.

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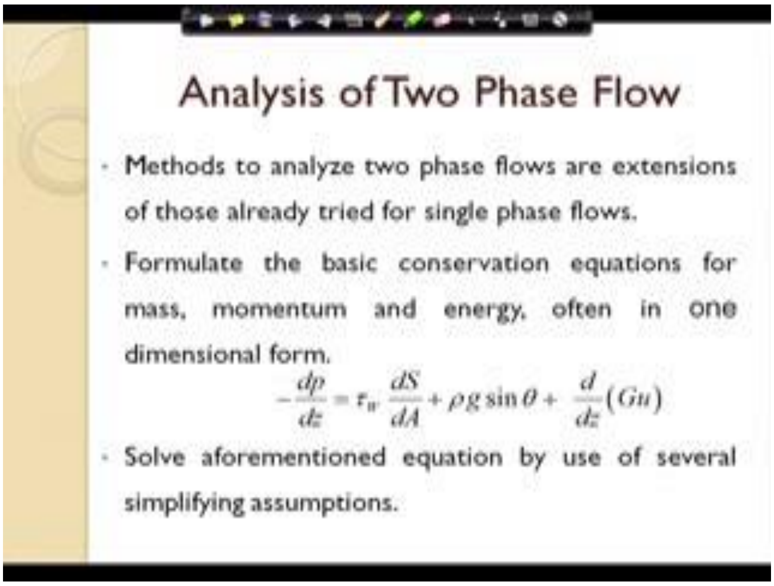

In brief, let us see what the general trend is in macro systems, because we will be flowing or rather we will be following the same methodology. In macro systems for two phase flow, what is the normal trend? We simply analyze two phase flow as or other similar to the methods which are used for single phase flow. What is the method used for single phase flow? We formulate the basic energy, rather the basic conservation equation for mass momentum energy. We develop the continuity equation, the momentum balance equation, the energy balance equation, the momentum balance equation, I have already written down.

And then based on some particular simplifying assumptions, we try to solve this particular equation, which has been develop for two phase flow. For two phase flow what should we have? Instead of this particular row, we should be having a two phase density, which should be a function of the densities of the individual phases and the composition of the two phase mixtures. Here we should be having two velocities when the two phases are flowing at different velocities, which is normally their case.

And in this particular case also, we should be having a two phase wall shear. So, therefore, what is done? The basic momentum equation for fluid flow, naturally it will be applicable for single phase or multi phase flow. So, that particular equation is developed and it is solved by using several simplifying assumptions.

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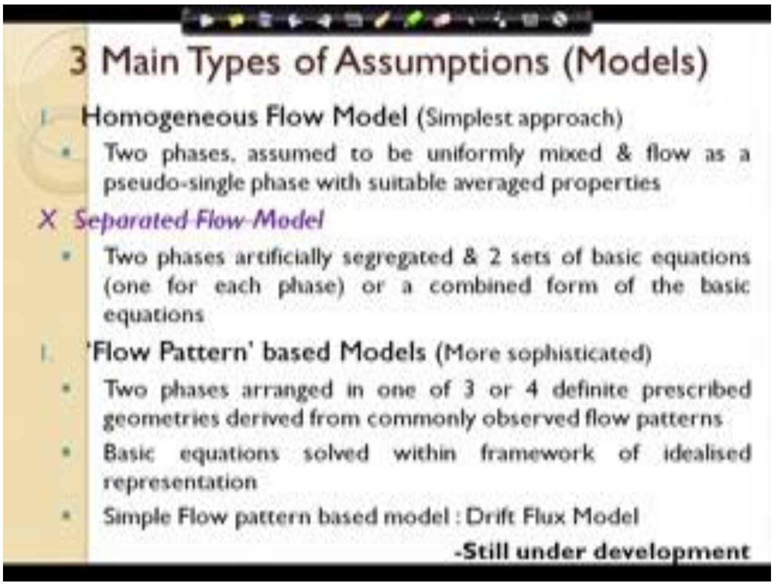

Now, a few assumptions are commonly used for macro systems. 1 assumption is 2 phases. They are assumed to be completely uniformly mixed and they flow as a pseudo single phase fluid with suitable averaged properties. So, in that case what happens? This same equation is applicable. We assume that both of them, since they are flowing as pseudo fluid, they will be flowing with one particular velocity and the both the fluids, as if there flowing as a single fluid, they will contact the wall and accordingly, a wall shear stress similar to single phase flow should be we should be able to define here and of course, the density it has to expressed in terms of the composition of the two phase mixture. This is one particular, this has simplest thing, which is done and this gives rise to the homogeneous flow model.

The other extremes, which we consider for macro systems is, 2 phases are artificially segregated and we write 2 sets basic equations; that means, 2 sets of mass, 2 sets of momentum and 2 sets of energy equations for the 2 phases and then either we try to combine the 2 sets of equations to form a basic equation and try to solve it.

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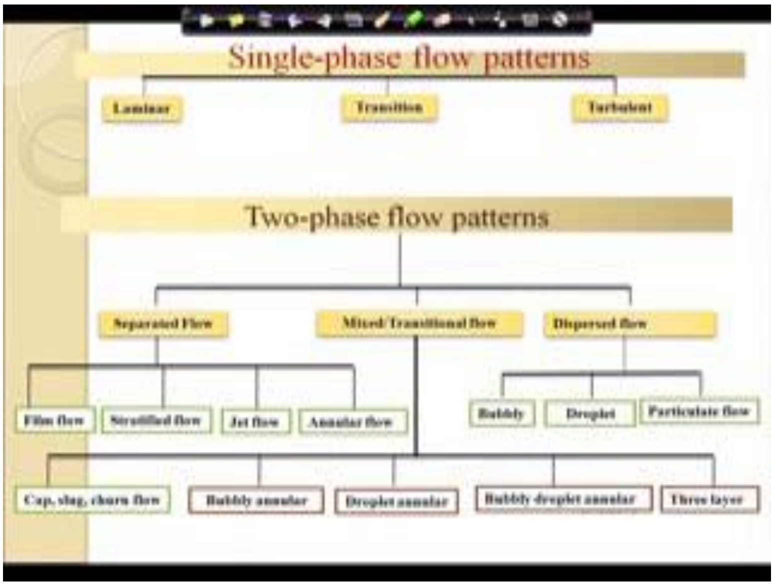

And the third thing which is the more sophisticated thing and which is still under development is we assume the 2 phases to be arranged in 1 of the 3 or 4 definite prescribed geometries, which can be thought of the general distributions of commonly observed flow patterns. For example, if we observe all the flow patterns that we have come across in our study on 2 phase flow, we find that on an average, they can be separated into 3 broad classes. 1 is the dispose pattern, 1 is the completely separated pattern and largest range is the mixed or transitional flow pattern.

So, therefore, we according to based on these particular assumptions, we can divide or rather we can assume that the 2 phases are, rather they are distributed in some particular commonly observed flow patterns. Then based on the flow patterns geometry that we have observed, we write down some basic equations and solve them with in frame work of idealized representation. So, therefore, for micro channels, we find that the more most commonly used technique is the homogeneous flow model and accordingly in the next class, we start discussing with the homogeneous flow model and we continue with some discussions on flow pattern based models. So, we stop here for this class.

Thank you very much.