Adiabatic Two-Phase Flow and Flow Boiling in Microchannel

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Lecture- 17
Void Fraction and Pressure Drop in Reduced Dimensions – Experimental Results

Hello everybody, welcome to the seventeenth lecture of on the adiabatic 2 phase flow and flow boiling in micro channels. What we were discussing in the last class, I think as was remember we had started discussing the lessons on void fraction and pressure drop.

What I intend to do today is I will continue with my discussions on the experimental observed trends of void fraction as a function of phase superficial velocities and conduit diameter as well as maybe I will touching upon the effective entry section just as I had done in the case of flow patterns and then we go on discussing the pressure drop.

Once, I discus the experimentally observed trends which have been observed then we go for the simple analytical models of the theoretical analysis of 2 phase flow specifically for micro channels.

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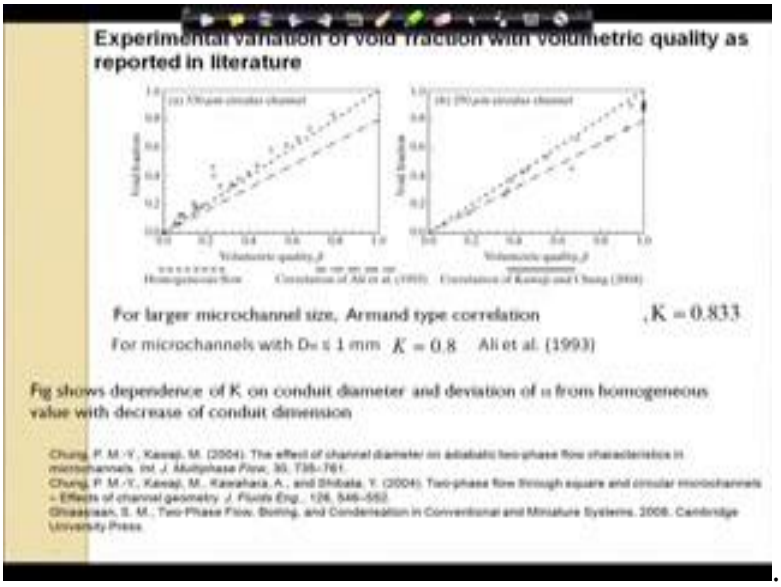

Now, if we go for the results we find that initially what do we find that may be if we take larger micro channels say 530 macro meter 250 macro meters these results have been

reported literature we find that for the larger macro channels more or less the void fraction it have been determined by image analysis and photography.

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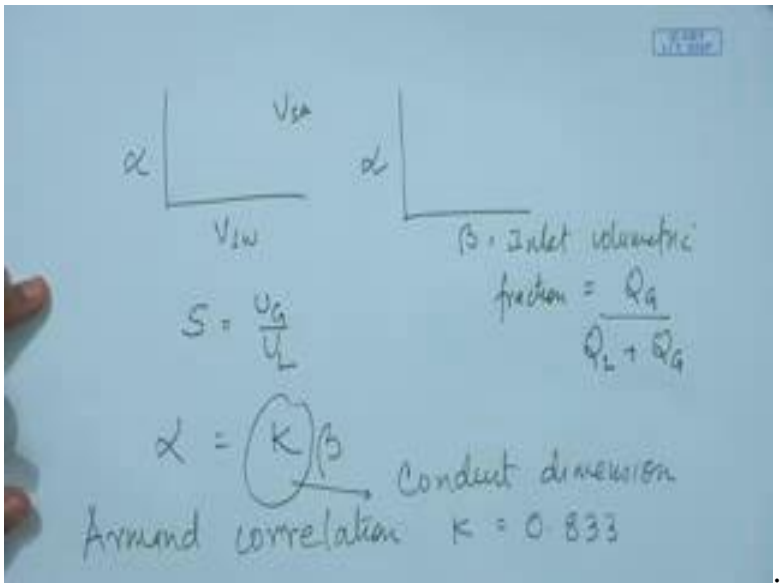

And there are conventional represented either as alpha verses phase superficial velocity it can be alpha as a function of your either water velocity with air velocity as parameter or in other words and the conventional way of expressing the radiation of alpha with superficial velocity is to plot alpha is a function of volumetric void.

If you re call the nomenclature part which I had discussed in the introductory lecture you will understand the beta is nothing but the inlet volumetric fraction naturally it is the ratio of the flow rates of the 2 phases if the 2 phases are gas liquid or vapor liquid then they can be expressed in terms of the volumetric flow rate of the gas flow rate and the liquid flow rate.

Therefore, if we plot alpha verses beta it gives as an idea regarding the slip between the phases where the slip can be defined as the ratio of the 2 velocities it show that how fast the lighter phase is flowing with respect to the heavier phase.

Therefore, in this particular case we find the researchers they have represented void fraction as the function of volumetric quality and we find that morals for the larger by dimensions alpha is close to beta although there is a trend of over prediction for the case of the 530 micrometer channel.

On the contrary, if we come to the 250 micrometer channel we find that there is the trend of under prediction, but never the less for both the cases we find that there is a linear relationship between alpha and beta for both the cases and the relationship which can be given of the form as alpha equals to K beta.

Where we find that this particular K it is a function of conduit dimension as it evident from these 2 classes. In this case I would also like to mention that such type of linear relationships have also been proposed for macro channels it was first proposed by Armand for their known as Armand type of correlation they were proposed with the value of K been close to equal to 0.833 and then this particular case we find that more or less K equal to 0.833 is not a very bad correlation is the correlation of Ali has used it for micro channel.

But a better prediction would have been point 833 in this particular case or sorry point 8 in this case may be point 9 in this case. We also find 1 more trend we find that the deviation from alpha from beta it is more at higher void fractions and if you recollect then we find that under these conditions the flow is actually annular and when it is annular then may be most of these betas have been obtained from image analysis and photographic technique.

Therefore, there is a high chance that at such high void fractions since the liquid exist as an annular film it is very difficult to estimate the thickness of the thin annular film in this macro channel therefore, this particular deviation has been attributed to inaccuracies inherent in the image analysis technique by the researchers who have experimented on this.

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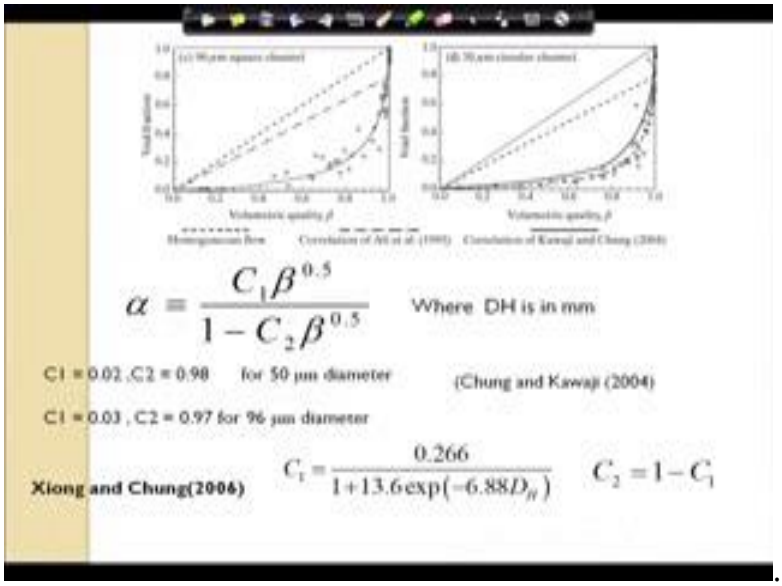

Now, we find that if we go to much low dimension of micro channel we fine that the trend has reverse completely in this particular case we find that it is the alpha is nowhere near beta and we if we observe it closely we observe low values of beta till about say beta equals to point 8 more or less linear relationship can follow this occurs in both the 96 macro meter as well as the 50 micro meter channel.

But after around point 8 we find in both the cases relationships becomes strongly non-linear and in fact it becomes exponential till alpha approaches the homogeneous value at higher values of void fraction also we observe that at higher values alpha does not reach it natural limit of one rather more or less it is round point 833 in both the cases.

It was quite evident that the relationship the Armand type relationship which was which has been used for the larger diameter piets with different values of K it is not vary applicable for the small dimensions. And accordingly, a correlation has been proposed for predicting alpha in this particular small dimensions; this correlation is applicable both for circular pipes sorry circular micro channels and also for square micro channels.

And it basically shows that when beta is small naturally the affect the denominator becomes almost equal to 1 and as a result alpha can be set to be proportional to beta although the proportionality is not linear and at higher values of beta the denominator becomes important as a result of which alpha predicts a different from linearity for higher values of beta.

Of course, several researchers try to work on to find out suitable values of C1 and C2 and it was noted that C1 all though it is weak function of diameters C2 was find to be constant by one group of researchers again there was another group of researchers who had suggested some different values of C1 where it was found that both C1 and C2 there are a function of hydrolyte diameter since this is also evident from experimental results we believe that the correlation proposed by Xiong gives better representation of experimental beta.

Now at this juncture I would like you remind you that it is not very important that we memorize these particular correlations at least for doing the assignments or the examination which will be held at the end of the class. On the contrary it is more important that you remember the form of the relation and also understand from physics why such a relationship does emanated or in other words why the alpha verses beta trend is different for your larger for micro channels and smaller micro channels from we would emphasize more on the physics of the flow rather than the mathematical form of the correlation.

It is again I will repeat that for this particular class you need not remember all the sets of correlations will be giving to you well be quieter number of correlations in this class since will dealing with pressure drop and void fraction, but it is again very important to remember why this correlation exists why the trend of alpha verses beta is different for your larger micro channels smaller micro channels and so on.

For example, in this particular case if I ask you that why does the trend suddenly change around to beta equals to point 8. And why is the trend different for larger and smaller micro channels.

In this particular case if you observe closely what do you notice? We notice that for smaller time we are lower values of beta what happens more or less for your beta varying between 0 to point 8.

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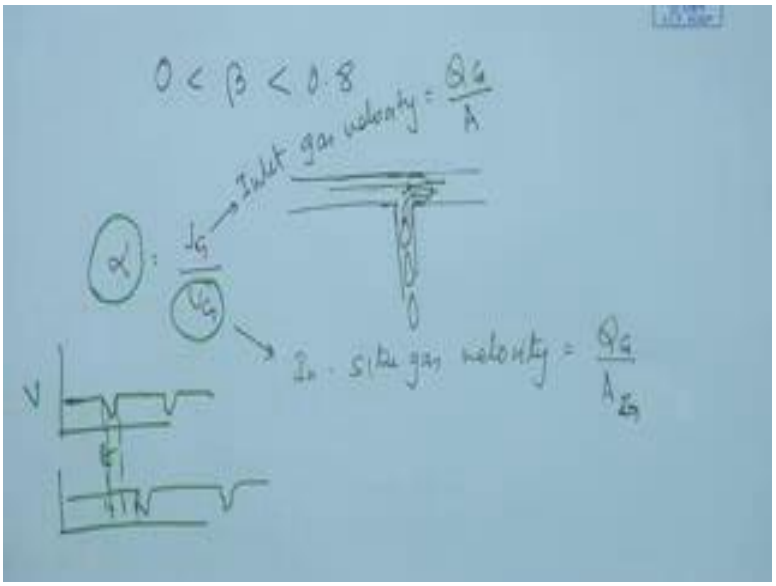

For this particular trends what happens you tell me short liquid slots and short the gas slugs they traverse in the micro channel right. Now whenever, there a short gas slugs because beta is low so therefore, naturally as we increase rather at lower values of beta we have longer liquid slugs compare to gas slugs.

Therefore, if we observed flow passage you should be see short gas slugs followed by long liquid slugs and so on. Now Fenevath Divya we have this long liquid slugs they increase the pressure gradient and when they increase the pressure gradient what happens the shorter gas slugs they tend to accelerate through the flow passage or through the liquid slugs and when there are accelerating 2 things happen. Firstly, when they accelerating the residence time decreases and when the residence time decreases naturally alpha comes down.

The other thing is from the measurement point of view when the residence time decreases they can very well evade that they have captured by the image processing technique ok. They travel so fast that they can hardly we caught by the photographic technique.

Due to these 2 factors very frequently we find that for beta ranging between 0 to point 8 more or less we find this particular trend for alpha it is much less than beta. Now what happened when beta exceeds point 8? We find under this condition the gas slugs they start becoming longer and longer and they are often intercepted by short liquid slugs

which can be in the form of liquid drinks, liquid lamb etcetera or in other word the liquid can just exist as a film and the glass slugs are long.

And the such cases what happens the 2 things again the same thing firstly, as the gas slug increases the pressure drop decrees so there is a lesser tendency of the gas slugs to accelerate and to travel very fast to the layer to the liquid slugs due to this the residence time of the gas slugs decreases and there is a greater probability of them being recorded by the camera. Firstly, secondly, as the gas slugs become smaller the residence time increases naturally alpha also increases.

This explains the nature of the curve which we find and this explains why this particular relation is suitable. Now if we compare them with the larger micro channels larger micro channel what do we find the gas liquid interface is much more wavy it is much more deformed as a result the gas slugs exchange far greater movement with the liquid and due to this enhanced momentum transfer it hampers the gas slugs from speeding through the liquid.

Naturally alpha is higher in larger macro micro channels as compared to lower macro channels this as explain 2 things 1 the degrees of alpha with degrees in conduit dimension the other is the non-linear nature in smaller micro channels.

Well just like the flow patterns we had discussed there is distinct affect of entry section we are also like to see the affect of entry section in this particular case as well.

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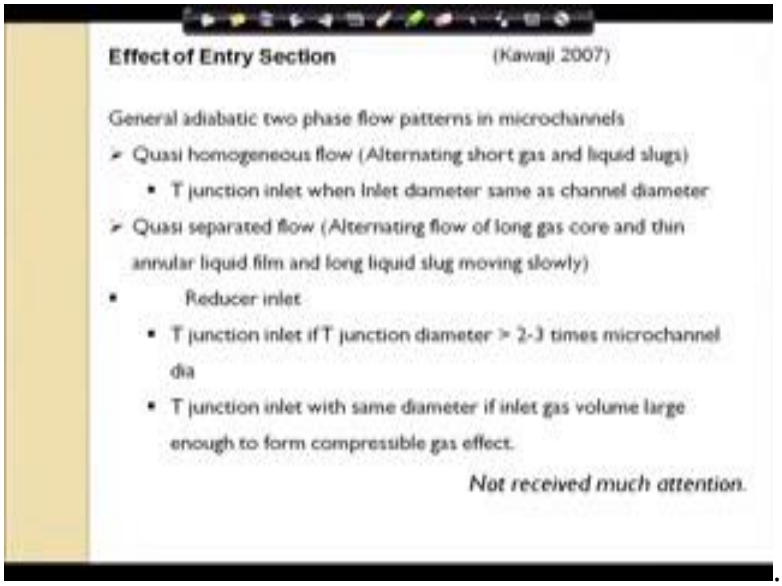

Now, what people have observed again it is it has been reported in literature by just one of two particular researchers and not much work has happened on this and these researchers they have also commented that the effect of entry section all though it has received very less attention this is definitely a very critical parameter for deciding the flow morphology and the hydro dynamic characteristics.

Now what is the affect that has been observed it has been observed that usually we know that the flow in this particular case can be broadly classified either as was he homogeneous which is alternated by short gas and a liquid slugs which happens at low values of alpha or it is quasi separated where it is alternating flow of long gas core and thin annular film and maybe there is a long liquid slugs which moves very, very slowly.

It has been observed that usually at T junction inlet it gives rise to the quasi homogeneous flow while I reducer inlet get rise to the quasi separated flow. Again, more important than memorizing this particular fact is, why might this at will happen? Because once you understand the logic it will be easier for you remember and appreciate the fact.

In this case it was observed that naturally when there is a T junction what we find this that the 2 phases they are flowing from the dynastically opposite points then liquid naturally has got a pinching affect on the gas the liquid it due to its naturally tendency of wetting it wets the pipe wall it fall something of this what and the gas it has to pierce

through this liquid core and then start falling and there sharing effect of liquid velocity it beaks the gas slugs into smaller gas slugs and this gives rise to the so called quasi homogeneous flow or it gives raise to the normal slug flow which we observe.

And when we have a reducer inlet what happens when we put a reducer both the phases they tend to get accelerated and, but naturally the gas slug it tends to get accelerated more. So, therefore, there is a greater tendency of the gas slugs to come closer to 1 another and to quails to form long gas coat somewhat similar to the annular flow pattern and therefore, it marks a transition between the slug and annular flow pattern and this explains why a reducer inlet gives rise to the quasi separated flow.

On the other hand a T junction inlet also give rise to quasi separated flow provided the T junction inlet is about 2 to 3 times greater as compared to the micro channel diameter why because in this case the pinching affect is counteracted by the reducer effect as a result the reducer effects becomes more prominent.

It can also occur from the T junction inlet has the same diameter as the micro channel inlet provided the inlet gas volume is so large that it can form or it can give rise to some compressible gas effect. Movement that compressively comes in to fact the gas slug it tries to accelerate and expand and accelerate at under a significant pressure gradient and naturally it gives rise to a quasi separated flow.

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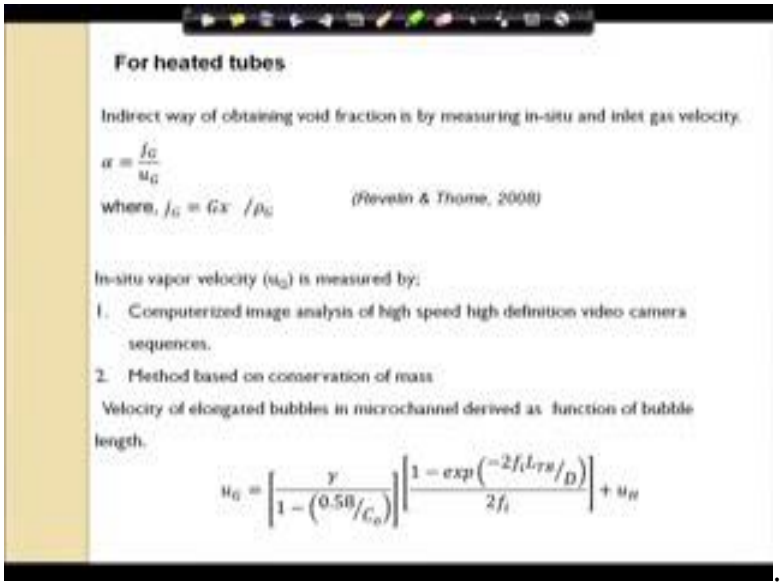

Now, with this we have already discussed you are the affect of entry section, the effect of conduit diameter, the effect of phase superficial velocities denoted as volume metric quality in term on the void fraction for adiabatic gas liquid cases.

Now, what happens heated tubes now as I have told you that for adiabatic cases usually photographic is the more commonly used techniques the other techniques are not so very much used and lot of the country intuitive phenomena it we observed were attributed to the errors involved in the measurement of very thin films or fast moving slugs etcetera.

Now, for heated tube usually how do we measure the void fraction it is almost the same we measure the flow pattern photographic is definitely one technique. Now for void fraction there is also an indirect way of measuring void fraction. How, is it if you remember the way we have defined the what is void fraction basically this is nothing, but equal to the inlet gas velocity denoted as the volumetric pluck divided by the inset to gas velocity this is termed as the inlet gas velocity which can be very well be defined by the volumetric flow a divided by the conduit cross section area and this is, the inceptive gas velocity it is naturally the volumetric flow divided by the cross section area that the AG the cross section area which the gas occupies when it is flowing along with the liquid in the conduit right.

Now, suppose we have an independent measurement of QG as well as UG then we can find out alpha from these measurements, measuring QG is not at all a problem we know the conduit dimension we can measure the inlet volumetric flow rate by any particular conventional flow measurement device and we can find out JG.

What about UG? Now, 1 particular method of finding out UG is by computerized image analysis of high speed high definition video camera sequences this we have discussed large number of times other than that there can also be a method which is based on conservation of mass.

This is particularly applicable for the pluck flow pattern which is much more prevalent in micro channel boiling 2 phase flow in this case the velocity of the elongated bubble in a micro channel can be derived as a function of bubble length and conduit diameter by defining a parameter gamma. What is this gamma?

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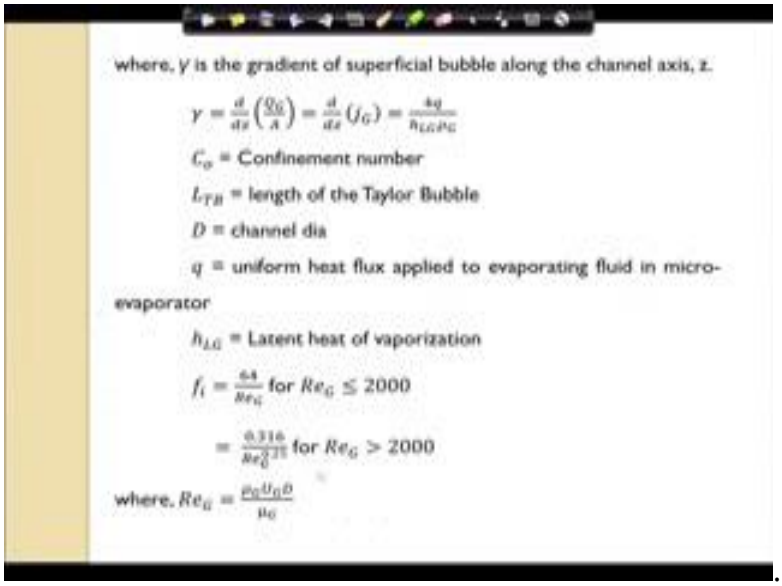

This gamma it is the gradient of the superficial bubble velocity along the channel axis. Therefore, what we do we define gamma as the gradient of superficial bubble velocity along the channel as axis assuming 2 things 1 is there is no liquid or vapor which is evaporating and the annular films surrounding the bubble is very thin compact to the micro channel diameter.

On the basis of these 2 assumptions the expression of gamma reduces in terms of the uniform heat flux applied to the evaporating field the latent heat vaporization and the density of the gas.

Now, once gamma is known and the length of the tiller bubble it can be estimated from photography then UG can be decided the velocity of the tiller bubble relative to the well homogenous flog velocity can be expressed by this particular expression you remember the CO is the confinement number by which we have define micro channels why we were discussing what defines a micro channel in one of my earlier discussions.

Now, from here we find out UG and once we have find out UG and definitely we can use this UG here and we can find out JG.

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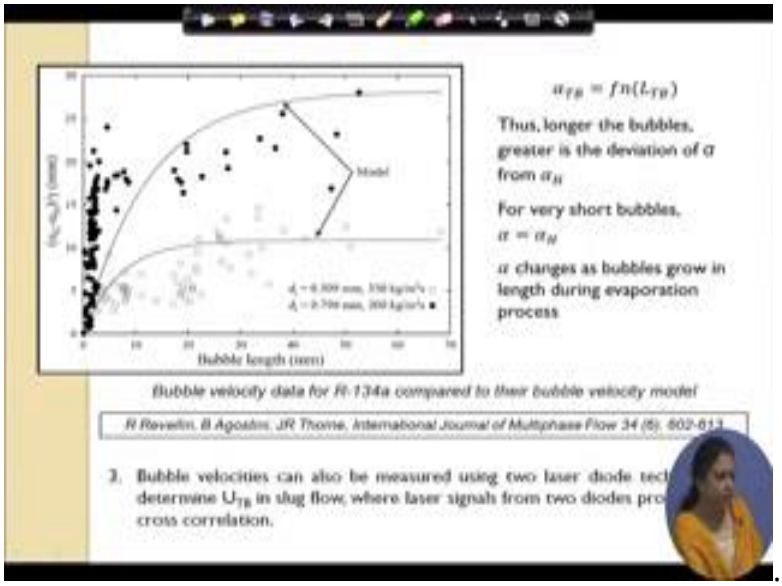

Now, several people this (Refer Time: 21:34) tried this out and there found from the expression the 2 things the alpha is a function of length and longer the bubbles greater is the deviation of alpha from alpha H.

Now this is what we had observed in our experimental results even in the case of your adiabatic cases as well as previous experiments performed in boiling heat trances we find that in this particular case we have shorter the gas lengths and shorter liquid plucks and its more of start flow and then the this case alpha was close to alpha H 1 particular reason of deviation of alpha from the homogeneous value was the change of flow patterns and the elongation of the gas slugs. This is also brought about by expression which has been derived from mass values.

And it also implies that as during heating or during boiling as the 2 phase mixture proceeds along the channel due to evaporation the bubble it close in length and as a result of it alpha keeps on changing we find that the increase of the velocity with respect to bubble length initially it is much more rapid and then it becomes much more gradual.

Therefore, there was 1 way of finding out UG by photography there was another way from the mass balance situation and the third way if you remember when we were discussing the experimental estimation of flow patterns we had discussed optical prop technique by this optical prop technique I had mentioned that we can know the distribution of the worlds which gives as an idea regarding the flow pattern.

Now suppose we have 2 optical props at known distance from 1 another and the these optical props if we note the signal then we find that for both the prop suppose this plot voltage verses time we for plot flow we get a signal something of this sort and for the other prop which is located at little distance a way we get a signal something of this sort.

Now if we cross correlate the signals then from the location of the value is we from this particular time intervals we can find out the time of travel of the pluck and knowing the distance between the 2 props, we can find out the tiller bubble velocity and since the entire gas flows as just gas plucks in this small channel.

They only give us the dimension of UG and once we know UG from here and we can measure JG we can find out alpha once more. Now in this particular case there is just one thing which has to be kept in mind the distance between the 2 optical props because if the distance is such that it is much larger than the length of individual plucks then it will be very difficult to capture the plucks.

Therefore, the spacing it should be optimum such that it can note the velocities for bubble slug or slug flow patterns if you would wish to use it bubble pattern the 2 prop should be brought closed to 2 another this has to be considered. So, this was for a heated tube this is a technique by which can do it.

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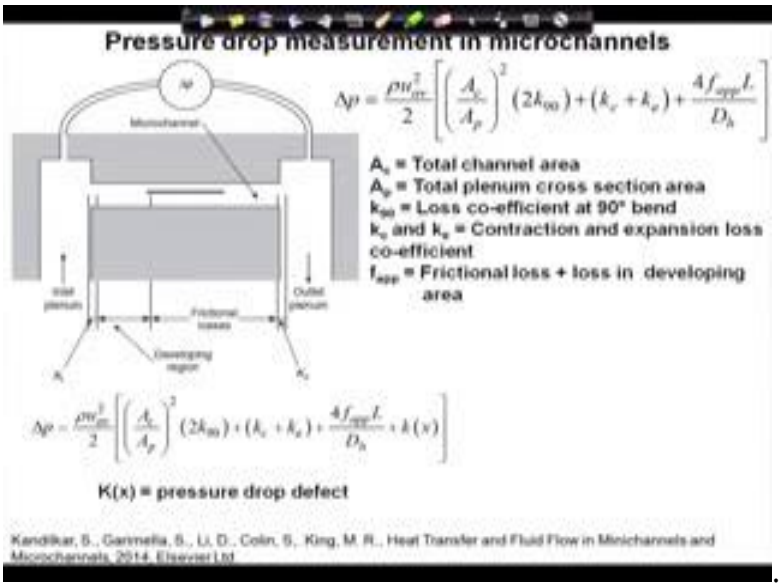

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Now, we come to pressure drop measurements now in the pressure drop measurements what we find is that most of the data in the mini channels and not much has been done, but whatever has been reported they are primarily for the mini channels and there is scarcity of experimental data as well as predictive model in micro channels.

Therefore, naturally some amount of results have been reported, but there is good amount of controversy and you find that this quiet a number of limitations of measuring pressure drop in micro channels. The first thing is that is quite obvious that the pressure drop in this case is primarily fictional is not it for therefore, and the conventional technique of measuring pressure drop is to connect the tapings to the inlet plenum and the outlet plenum and measuring the pressure drop between these 2 because, it is very difficult for making pressure tapings at the intermediate positions the thing which we do for larger channels we have to pressure taping in the regions which we consider as the fully developed flow then, we measure the pressure droplets, but that is not possible for the case of micro channel and this is the conventional thing which is usually done.

Now when this particular technique is developed then we find that there are quite a number of limitations and uncertainties associated with the pressure drop measurement in this particular case.

In the next class we will be discussing the uncertainties associated with pressure drop measurements we will be discussing some typical pressure drop results for oil water and the air water flows and then we will be shifting to the analysis of 2 phase flow in micro channel.

Thank you very much.