Adiabatic Two-Phase Flow and Flow Boiling in Microchannel
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Lecture - 11
Flow Regimes and Void Fraction Estimation.

Well, hello everybody, once more welcome to the, to our discussions on the (Refer Time: 00:28) determination of Flow Patterns and Void Fraction. We were discussing, if you recall, we were discussing the impedance prove technique, where the, the Void Fraction or the distribution of the 2 phases, they are determined based on the difference in either the electrical conductivity of 2 phases, or the electrical capacitance of the 2 phases, and we are discussed the advantages of the impedance techniques, and I also had told you that for micro systems usually arc electrode probes, they are used where.

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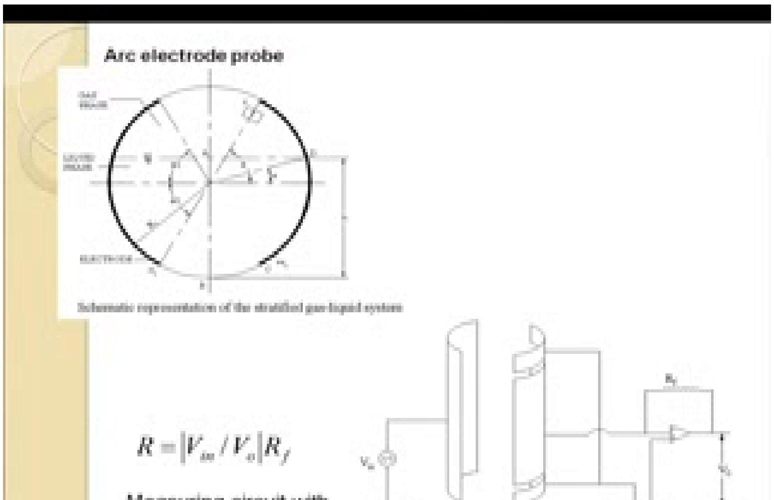

In this particular case you can see the arc electrode probe is of this particular design, which are used in macro systems.

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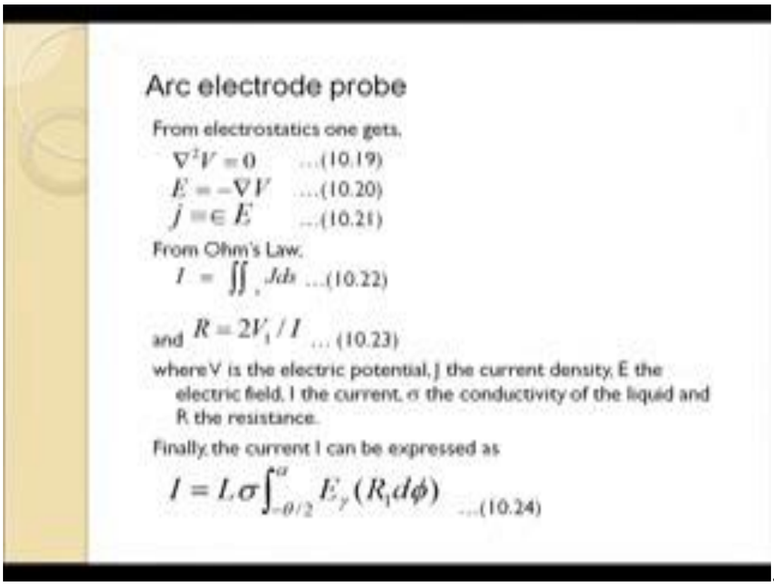

And for this arc electrode probes, we find that based on electro statistics, the following derivation can be done.

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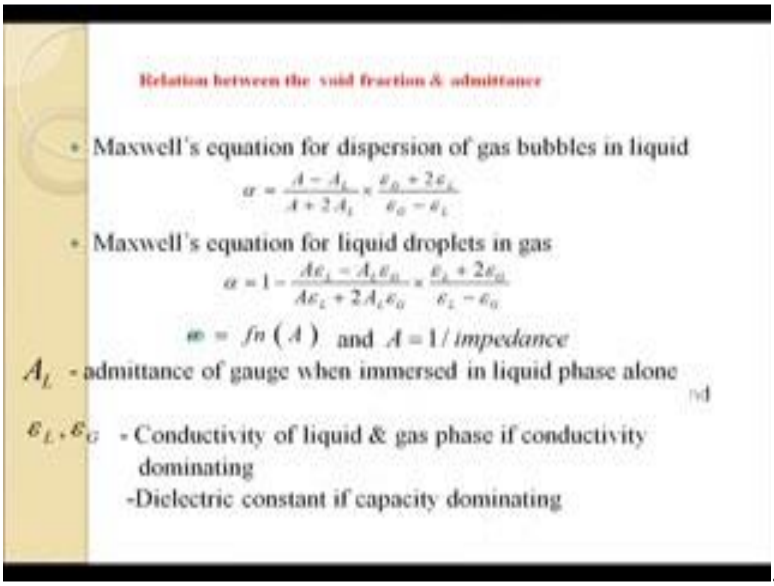

Forms which we can find out a relationship between void fraction and admittance for 2 difference cases, one is dispersion of gas bubbles in liquid, and the other is liquid droplets in the gas.

For any other sort of distribution, the mathematical derivation has not been done in that way, and we know very well that none of these distributions are applicable for micro systems.

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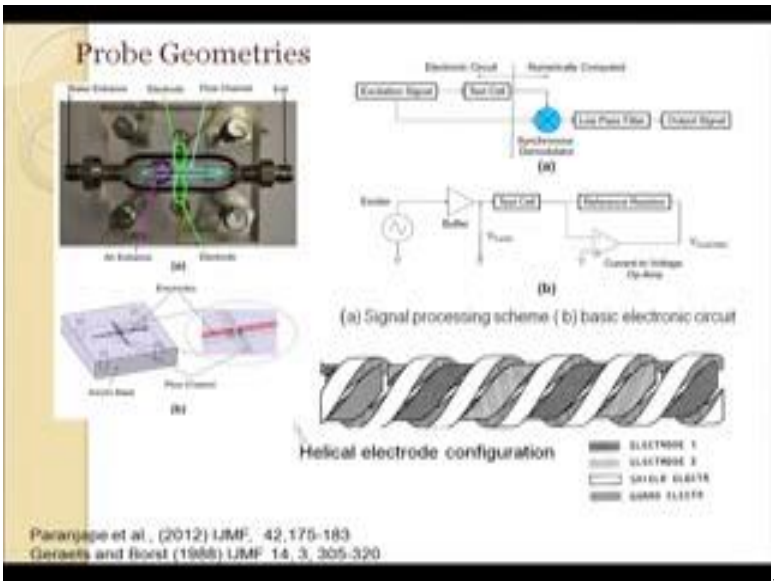

Therefore, what is usually done is, as we are discussing, generally sense nothing intrusive can be done here. Although a large number of varieties of probe designs are available, failure, the in macro systems, namely the grade electrode probes the point electrode probes, but usually the area average arc electrode, modified version of arc electrode probes are usually used, and had all ready discussed this particular design of the probe.

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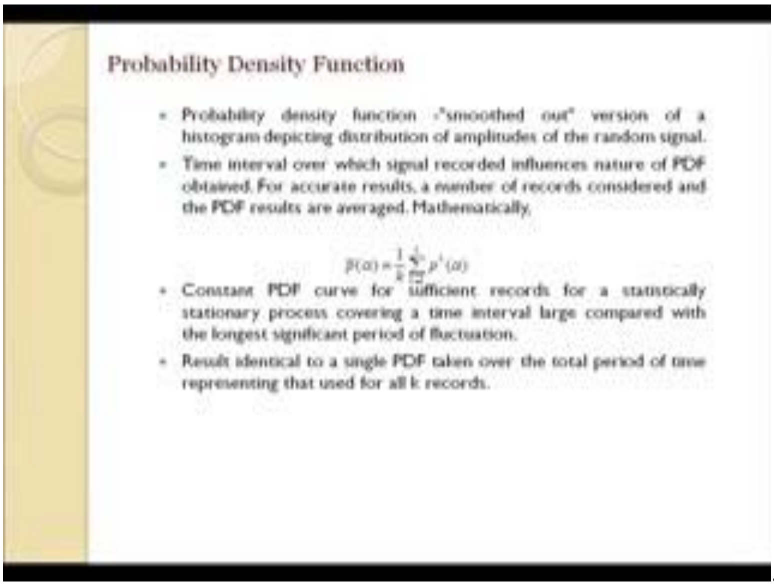

Now, since these things were not very available. So, usually apart from the raw signals people usually have performed the Probability Density Function analysis of the random signals. Now as I had all ready discussed, or the curves generated, or the Probability Density Function curves obtained from an optical probe, and at that time I had told you, that I will discussing for the PDF for a Probability Density Function is, after sometime. In this particular case I would like to discuss this, before discussing the PDF curves generated from the random signals.

Now, the PDF curves they are nothing, but the smooth out version of a histogram, which depicts the distribution of amplitude of the random signals. And the time interval over which the signal is recorded, it influences the nature of the PDF. For example, suppose you are recording, is quite evident, suppose you are recording the signal for a very short while, suppose it is slug flow and you are recording the signal for a such short while, that it just can capture the situation, where the trailer bubble is traversing the, the optical probe, or the impedance probe, whatever.

From that particular signal, if you want to derive some information, it will appear that it was actually annular flow, with a continuous gas code, and may be some amount of liquid film. Or in other words, if the recording is so very less, or rather the recording time is so very less, that just the liquid slug is captured, or may be you have captured 5 liquid slugs, and may be the 3 short tailor, sorry 4 short tailor bubbles, then it may appear that either only liquid was flowing, or maybe it was a bubbly flow pattern.

Therefore, in order to obtain a proper, rather a proper idea, proper appraisal of the flow situation, it is very important to see, that the time of recording is quite high. And so, this particular the, this influences the Probability Density Function curves and so, therefore, either the recording is done over a large amount of time, or in other words, large number of recordings are done, and all of them are average properly in order to obtain a reliable Probability Density Function curve. And it is quite obvious that therefore, a constant, and if you record it for a very long period, then naturally we will get the nature of the curve, which will be, which will not anymore depend upon the period or the time of recording, it is quite natural.

If you record the signal, for such amount of time, which is larger than the fluctuations in the flow signal, then naturally what we get? We get a stationary PDF. For example, in the for the bubbly flow we would get 1 a uni modal PDF, with a large voltage, rather with the large peak, at either a low voltage or a high voltage, depending upon what type of circuit, and what type of measurement technique we have taken.

If during water flow, the output is a low voltage, then for bubbly flow we will be getting are uni-modal peak get low voltage, if during water flow we get a high voltage peak, then for bubbly flow, the uni-modal peak with obtained that high voltage, just the reverse happen for annular flow. And if we are taking the signal for a very large amount of time, then we will find, that we can differentiate between wispy annular flow, and liquid rink flow, and slug flow, and maybe dispersed flow, because all of them, for all the signals, there will be some particular differences, in the PDF curves.

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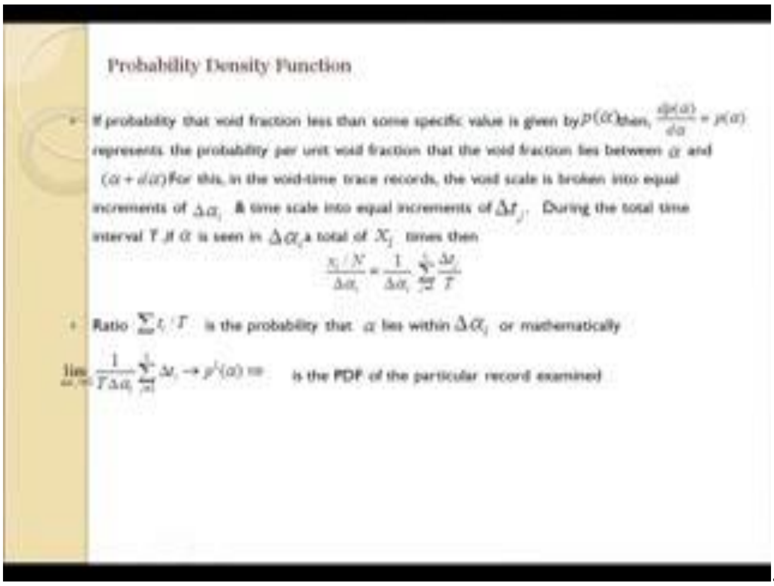

It can be either in the mean value, or it can be in the, in the, the standard deviation, or the spread of the PDF curve.

Depending upon all these things, we are going to get different curves, for different Flow Patterns, as we have already seen for the case of optical probes.

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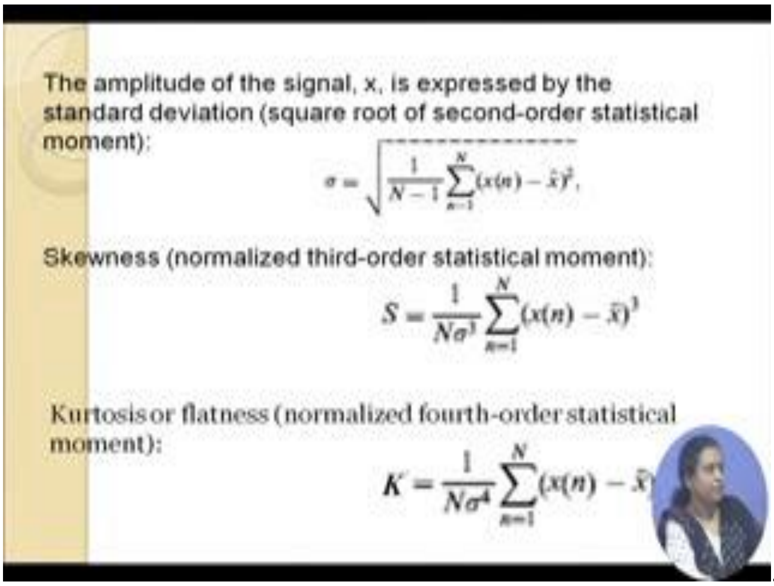

And usually the, these, the moments of the PDF curves, their number one is the mean value of the signal, which gives you a rough idea regarding the average proportion of the

2 phases, and of course, it this is the derivation or other the this is the expression I should say, of the standard deviation of the signal, and the nature of the peakedness of the other nature of the spread can be obtained from the skewness or the kurtosis.

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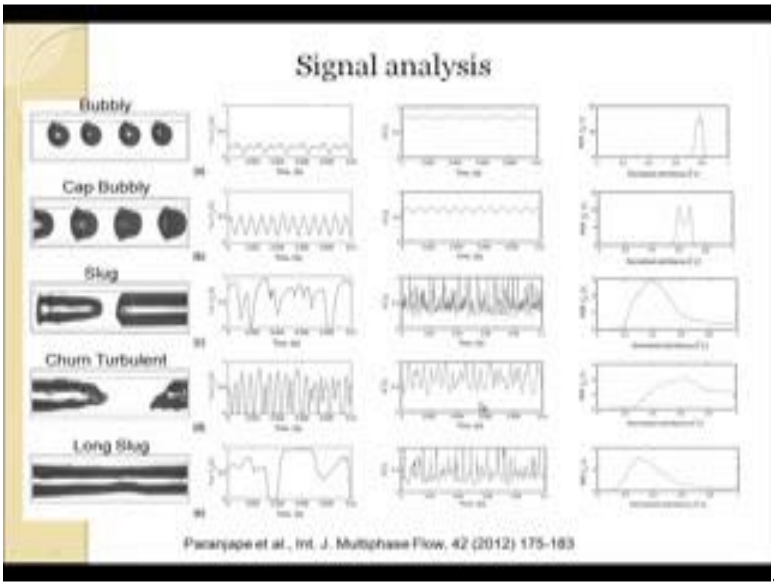

Now, let us see what is the different type of signals, which had been obtained by Paranjape Et Al for the different flow situations they had encountered in a micro channel quite naturally, we would observe that, thus, from the, the just the direct visualization of the row signals, it was always not possible to differentiate the Flow Patterns.

If you observe this particular signal and this particular signal, just from the basic appearance it appears, that, they might be something similar, and we find that a better appraisal of the flow situation was obtained, once the Probability Density Function curves your taken. What do you observe in this particular case? Just like optical probe case we observed that for bubbly flow, we have we have obtained a peak at a larger value of voltage, right? Quite naturally, because and water is flowing, then the circuit, these circuit gives higher voltage. So, therefore, for bubbly flow, we have obtained a uni-modal peak, at a higher voltage and there is a small spread unit.

From bubbly flow as the bubble start becoming slightly larger and the form this cap shape, very interestingly, in both the cases, water is the continuous phase, and therefore, the other the peak occurs at more or less high voltage, the peak from bubbly to cap bubbly flow has shifted slightly to lower voltage, but more importantly we find, that the peak in this case is bimodal, unlike the uni-modal peak we have observed here. So, this shows that the cap bubbles are traversing the flow passage at, at a frequency and the size large enough to make an independent presence.

Therefore, we find that a bimodal peak, the considerable spread, marks the domination of the bubbly flow, and the onset of the periodic flow appearance. Now again, if incase the gas velocities increase, we find that the cap bubbles they start becoming longer and longer, and the form slug flow. So, this particular case also, there is uni, sorry, a bimodal peak, but it is quite natural, that the peaks are much further apart. In fact, the second peak is not very evident in this particular case, it occurs very close to 1. So, this shows that the slugs are firstly, increased in length, it is quite evident, and the first peak it has shifted to much lower voltages, indicating the greater residence time of this slugs and this case. It also indicates shorter liquid plugs and, but more or less, the bimodality being retained, shows that both of them denote the periodic flow pattern.

From here, once we go to the slug, I should say it is the slug annular transition, which people have called as the Churn Turbulent Transition. If you if you observe the raw signals, you find that it is extremely erratic, and if you observe the Probability Density Function, you find that in this particular case, the 2 peaks are not evident, the entire output, the curve appears to be a single spread out curve, with a large value of skewness, and there is no definite peak, but it is a spread out phenomena, at a higher voltage.

And as this particular the, gas slugs they start qualising with another, to form long slugs, till now let me tell you, annular flows has not appeared, this results have been taken in a typical micro channel of some micro meter dimension. Therefore, bubbly was obtained, even if you observe the bubbly flow pattern, you will find that there more or less this shaped, large bubbles, and we have not observed, all though these appears to when annular flow pattern, there has been some bridging and some particular point. That is in this particular case what do we have? We definitely have a uni modal peak; the uni modal peak is at a lower voltage that is also true. And we also see that there is a large spread out portion, which shows the presence of occasional liquid bridging, in this particular case.

Therefore, in this particular case, the thing which we obtained is, we find that for the case of long slugs, we have a spread out peak. Although just from the basic appearance, it is very difficult to differentiate between the, the different Flow Patterns, but from the Probability Density Function analysis, we are able to do the same, right? Now there was another type of impedance probe, which was also adopted in literature, well, I have represented this particular probe, in that, this was used by the second group of researchers that I have mentioned. In this particular probes it is very interesting, here what do they have? They have got 2 electrode, which a flush mounted to the 2 walls, which more or less it is signifies, rather it is sort of the arc electrode probe, which is used for micro, sorry, macro systems.

In this particular case, what do we have? There are heli, this is a helical electrode configuration, and where if you observe, one particular electrode, it is wound like a helix, on the conduit, and the other electrode is also wound like a helix, which is opposite to the first to electrode. And along with that, there is a shield electrode between the 2. This particular shield electrode, it fixes the stray capacitance, and makes an analytical approach of the helical cross capacitor possible, and we find, that at both the ends, there are guard electrodes, if you observe at the 2 ends there are the guard electrodes. These guard electrodes are placed to render age effects negligible, as I have already discussed for the case of macro systems.

The guard electrodes are connected electrically to the 2 shield electrodes. Therefore, in this particular case we find, that the design is the bit more involved in this particular case, and the results or the output from the measurements, of the flowing current, between electrode 1 and electrode 2, have been depicted in this particular signal.

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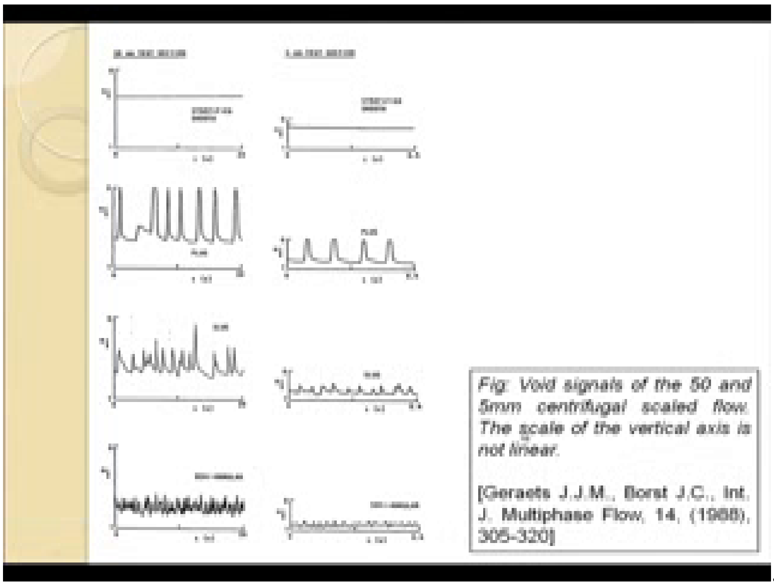

Well here of course, they have used the same probe, for a large cross section as well as for smaller test section, definitely it is a mini channels, therefore, stratification occurs here. If you observe these signals, then in that case you will find that it gives you for smooth stratified, quite expectedly it gives you an almost straight line.

The plug and slug flows, they are very evident from the intermittent nature, which shows the tailor bubbles and the liquid slugs, and for this semi-annular case, we find that it gives a small fluctuating signal, at low value of voltage, which signifies a continuous gas core, and slight deviations due to the presence of small amount of waviness in the interface of the liquid film and the gas core.

Now, let me tell you one thing that this was used for 2 particular dimensions, where one was a macro system, the other was, was the mini system, now in both of these as we have all ready seen the patterns were morphologically the same. There was slight differences which could be captured by the probe, but we are as yet not sure, how well this particular probe would be performing, for a micro channel, where the entire distribution was different variations of slug, and we would have to capture the differences between the slug, as has been done by the modified version of the arc electrode probe.

This could capture the variations between cap bubbly slug etcetera, particularly after the Probability Density Function analysis was performed. On this particular slide, it gives as a very good idea or an objective idea, regarding the distribution of the 2 phases, in the mini channel and a macro system. If you observe the annular on the semi annular flow pattern, just like comparing the 2 signals, it is automatically evident, that the amount of interfacial waviness is less here, it is much higher here. Then if you compare the slugs and these 2 particular cases, you find that, the slug flow pattern is marked by a greater amount of disturbance, as compared the slug flow pattern here.

In this particular case, more or less, we have straight, more or less we have peaks, and we have got straight valleys, well in this particular case, we hardly have an a straight valleys. The primary reason being the aerated slug, liquid slugs in this case and the un-aerated liquid slugs in this particular case. So, therefore, we, from here, we find that as far as micro channels are concerned, for the measurement of Flow Patterns, the most wide spread technique is the Flow Visualization and Photographic Techniques, accompanied by suitable image analysis, of the different techniques, rather, sorry of the different images. Few researchers have attempted to develop an Objective Flow pattern indicator, either by using the Optical Probe method or by using the Capacitance Technique.

Now, remember one thing, whenever they had used even the optical probe, the intensity of the incident laser had to be much less, and for the Capacitance Probe also, although conductivity probe is more popular, for micro system, but in micro system usually, the Capacitance Probe has been used, and we are also seen that the Probability Density Function analysis, has led to an enhancement of the amount of useful information, that can be obtained from this measurement device.

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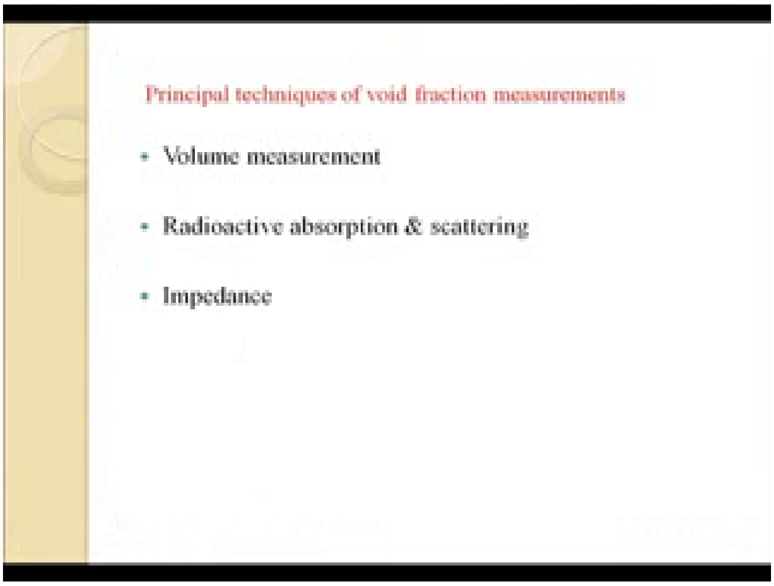

Now, at this particular juncture I would also like to tell you, regarding a brief idea about the Void Fraction measurements, right? Now flow pattern estimation means nothing, but measuring the distribution of the voids right? But if, if you want to find out any useful property, of the 2 phase mixture, say it is the 2 phase, you have the 2 phase density or the pressure drop, we would want to have, apart from the distribution of voids, we would like to have the average Void Fraction. Now how can we measure this? The common, the most common technique to measure Void Fraction, is, for macro systems is typically the Quick Closing Valve Technique.

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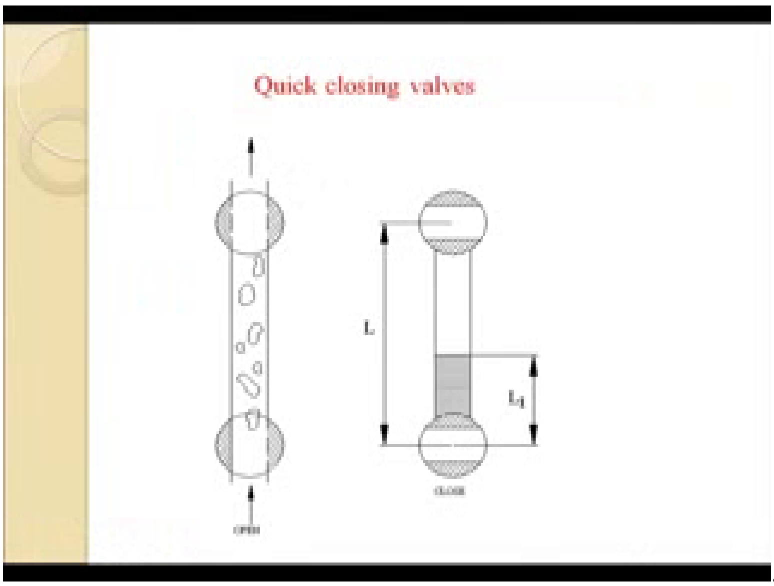

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What does the Quick Closing Valve Technique do, let a say it is the simplest technique, simply in the flow passage, we have 2 valves, or 2 quick closing valves located at the 2 ends. When we have ensured that the flow is fully developed, steady state, simply, the 2 valves are closed simultaneously, in one particular instant, and the 2 phases are trapped between the 2 valves, the trapped 2 phase mixture, is then separated out, or it is separates by gravity, and the volume fraction of each is noted to find out, the Void Fraction of the flowing to phase mixture.

This is the most common and the most reliable technique, for macro systems, and any other more sophisticated techniques which are much more popular, say the Radioactive Absorption and Scattering Techniques, or the Impedance Techniques, all of these have to be calibrated with the Volume Measurement technique, or the Quick Closing Valve Technique, in order to obtain or reliable estimation. Unfortunately or fortunately the Quick Closing Valve Technique cannot be used for micro systems.

Firstly there are some fabrication problems, you cannot fit 2 valves and all those things, that is definitely there, but more importantly we find, leave alone micro channels, even if you dealing with mini channels also, we find that the 2 phases do not separate by gravity.

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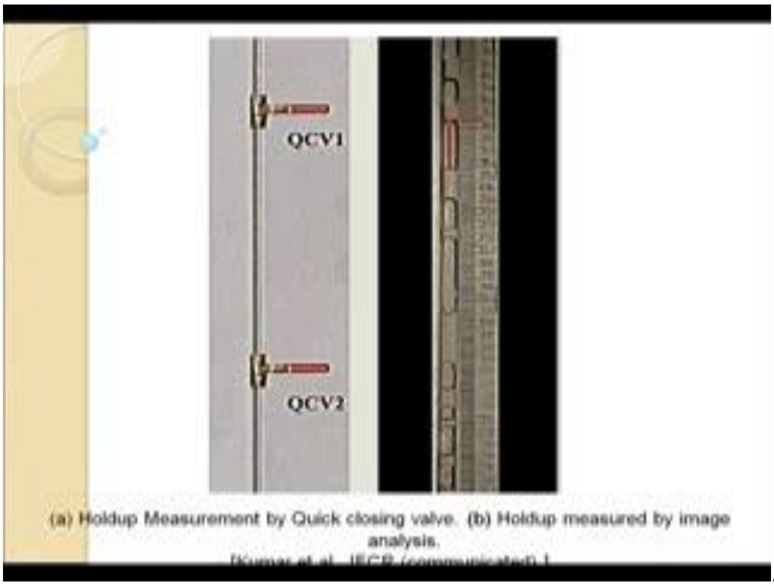

Even if you are working with a air water system also, they do not separate by gravity, on simultaneous closure of the valves. This is evident in this particular slide, this is again taken from the, from some of these experiments performed in the multifaced laboratory of the chemical engine department.

We find that we have been working with the 4 millimeters and 2 millimeters tube, and simultaneous closure of the 2 valves, the 2 phases do not undergo gravity separation, rather one of the, the gas phase it remains as stationary plugs, in the continuous liquid phase. That is in order to find out the Void Fraction, in this case also, along with the Closing Valve technique, the Photographic technique and Image Analysis had to be performed.

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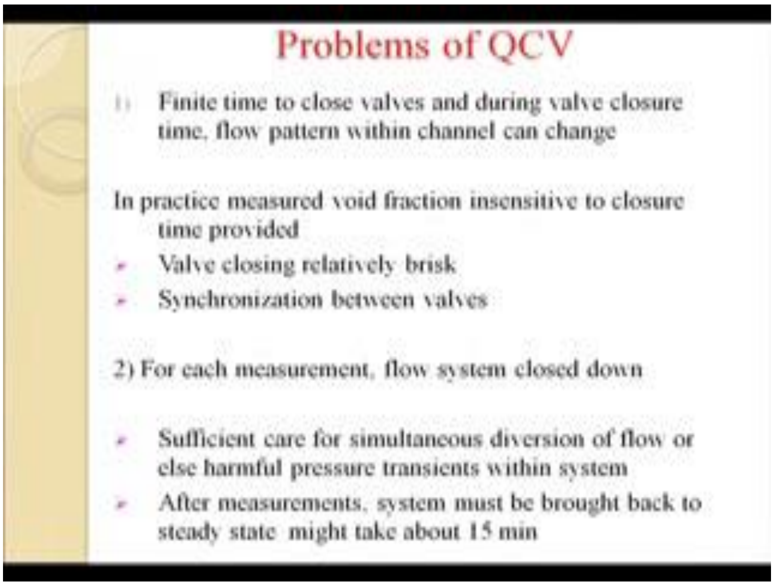

Therefore, the, we find that the basic technique which is used for macro systems, it is not suitable for micro systems. Definitely the, the quick closing valves techniques has got a large number of problems even in macro systems, we are not going to discuss them, because it is not applicable for micro systems. There is no point in wasting our time over it.

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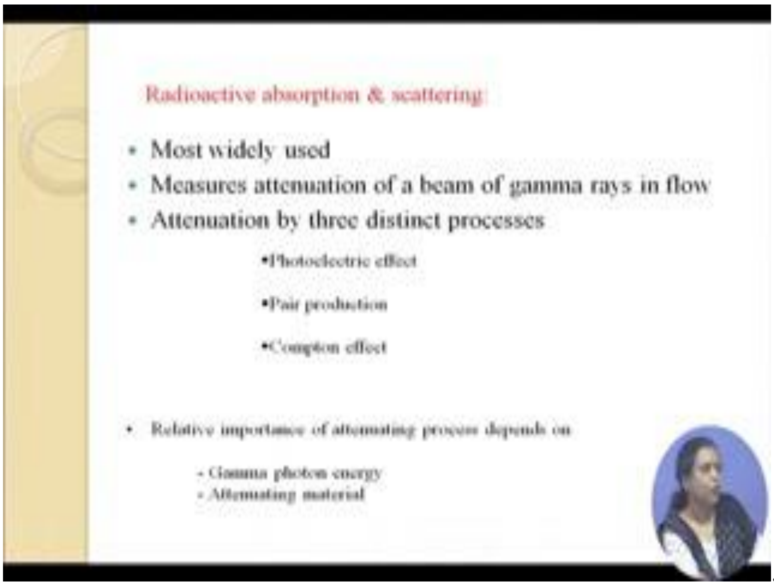

As a result what we find is, that in order to measure the Void Fraction, we have to take resort of the techniques which we have already discussed, but let me tell you, till now, the majority of the researchers, who have worked or rather who have experimented with the void, or rather who have tried to estimate Void Fraction, they have used the Photographic and the Image Analysis technique. The radioactive Scattering Technique which is very popular for macro systems, have not been used with much success in the micro systems.

The reasons are firstly, the radiation amount, or the incident radiation has to be of sufficient low intensity, in order to measure the amount (Refer Time: 24:32) by the 2 phase mixture.

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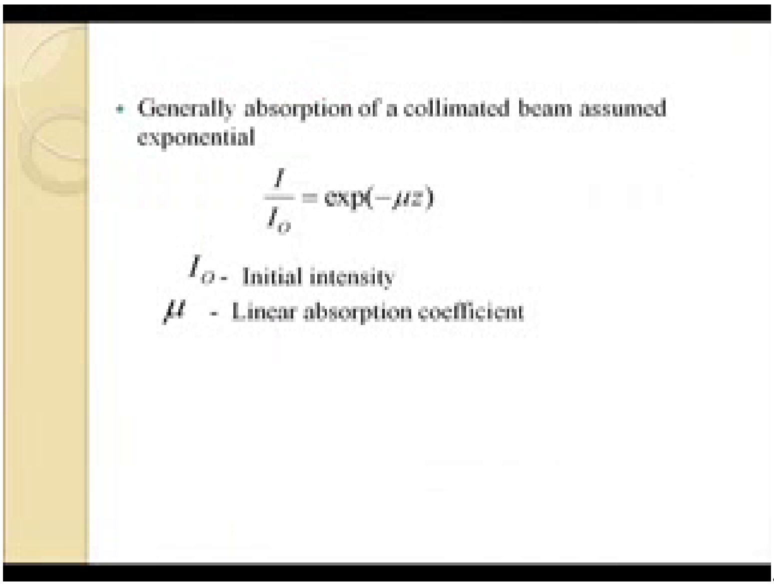

The volume of the 2 phase mixture is so less, that the amount of attenuation will be very less, and from here it is it is very evident, that the, the measured intensity, as a function of initial intensity this particular ratio will be quite large, because the linear absorption coefficient as well as this z, the actual distance of travel of this particular radiation, both of them being very small. Therefore, I by I 0 will almost be equal to 1. That is why, very difficult to measure, such a small amount of intensity which has been absorbed. And the other thing is we find out that, well so, for that particular reason, and when, the amount of, amount which has been absorbed attenuated is so small, then naturally the uncertainty or the error associated with the measurement also becomes very large, this is number 1. Radiation absorption cannot be used, or it, is not it is very difficult to use this radiation absorption in micro channels.

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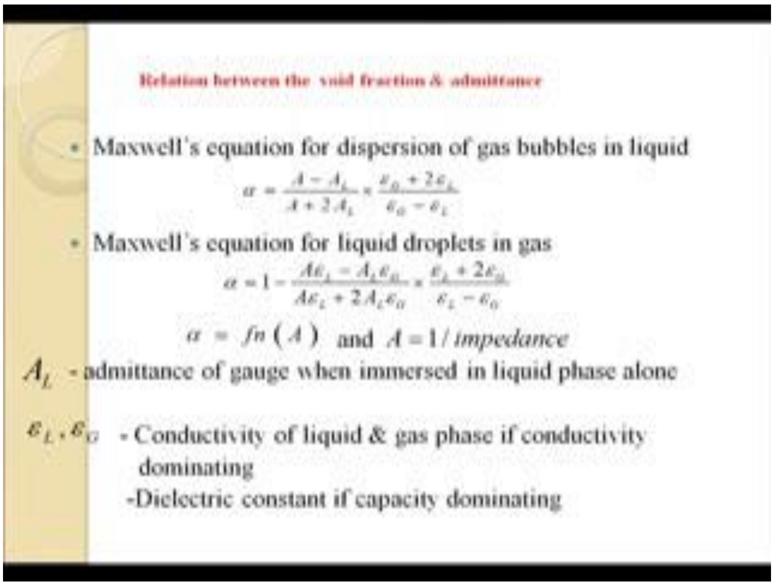

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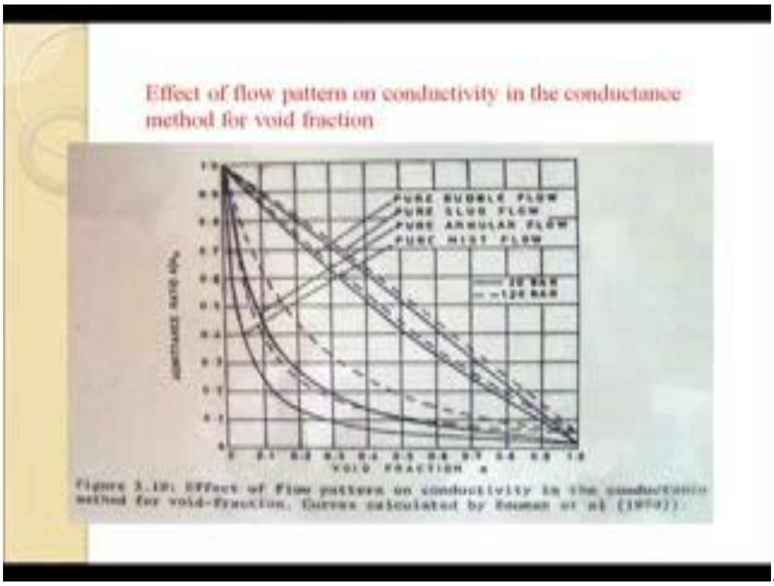

Now, about the Impedance Probe techniques, impedance Probe for the we find we find that as I am already mentioned, the relationship between Impedance, and Void Fraction that is the very sensitive function of flow pattern, and unless we know flow pattern, it is very difficult to obtain and idea regarding the interfacial distribution. And as I have already said, that estimating flow pattern itself is not very easy, fabricating of probes for a micro channel, that is also very difficult. With all, and the other important thing is, you have to remember, that in order to obtain and accurate quantitative estimation of Void Fraction, using the impedance probe, it is very important that we have an accurate estimation of the conductivity of the liquid phase and the gas phase, and since the conductivity changes with large number of parameters, it is very difficult to obtain a proper estimate. The other thing is, if you have to obtain a proper estimate of the Void Fraction, it is important that we have an (Refer Time: 27:13) knowledge of flow pattern, and this itself it is difficult for micro channels.

With this I end my discussion, on the experimental techniques of determining Void Fraction, and the Flow Patterns, or the distribution of the voids, we find that all said and done, we still rely on Visualization Technique, including Photography and associated image analysis, both for estimation of Flow Patterns, as well as estimation of Void Fraction. In the next class, we will first be discussing regarding the, the influence of several operating parameters, on the distribution of the 2 phases, and then we will shift over to the discussion of the variation of Void Fraction, with different input parameters.

Thank you very much.