Adiabatic Two-Phase Flow and Flow Boiling in Microchannel

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Lecture – 09
Experimental Identification of Flow regimes

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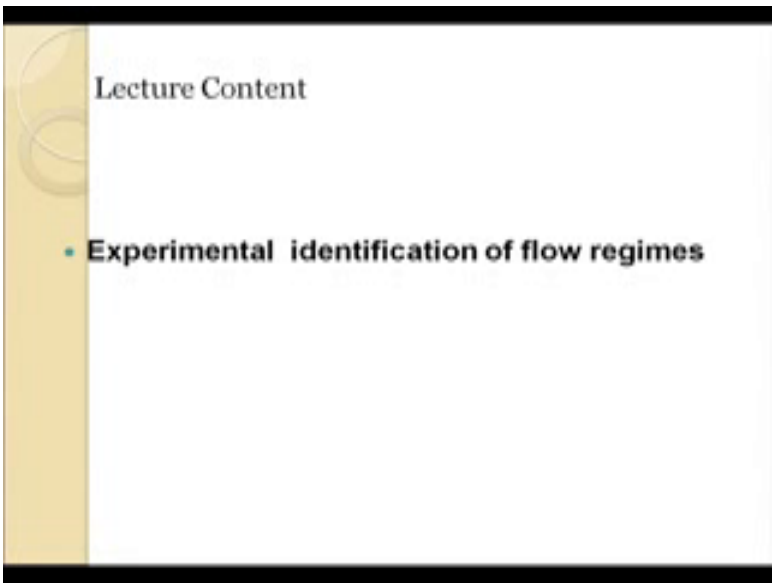

Well, hello everybody.In this particular lecture series we are going to discuss the experimental techniques first for identification of flow regimes and then we discuss a little about the inference of different operating parameters on the distribution of the 2 phases primarily those parameters which influence flow in micro channels, but not so very pronounced effect in micro channels.

And after that will go about the experimental estimation of wide fraction what are the challenges involved experimental estimation of pressure drop and what are the challenges involved and then after that we go for the modeling part.

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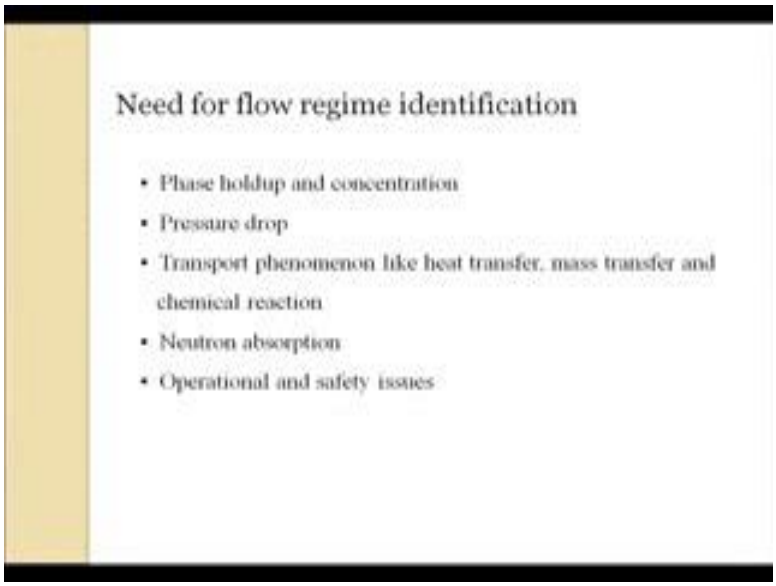

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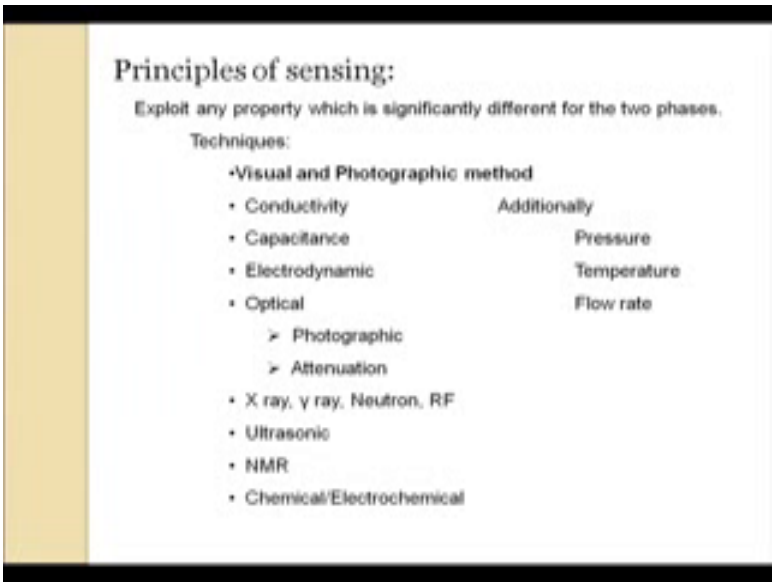

Now, as far as flow regimes are concerned we find that sorry normally for macro systems we find that there are several different ways of sensing flow regimes out of this different ways the most is the most reliable I should say (Refer Time: 01:28) oldest technique whatever you say at the visualization techniques which are based on visual and photographic techniques.

Other than that very common way to detect the distribution of the flow patterns as well as estimation of wide fraction is to explode any particular physical property which is

different for the 2 phases. This particular physical property can be indifference in the electrical impedance of the 2 phase it can be difference in electrical conductivity or a difference in the capacitors of the phases for air water system conductivity probes are widely used in macro systems and they got a large number of advantages as well situation been seeing shortly.

It can happen that the 2 phases they have widely different optical property say difference in refractory index or a difference in absorption coefficient this difference in absorption coefficient is a very common property which is exploited particularly for liquid system where intrusive conductivity or capacitors probes cannot be used very free and other than that we can use any other physical property which is different for the 2 phases it can be a difference in the attenuation of gamma ray, X ray, neutron it can be an ultra sonic probe which measures the difference in the in the amount of absorption of ultrasonic waves and so and so forth additionally we can also measure the fluctuations in pressure temperature fluid etcetera or so.

The basic principle be that we try to find the distribution of the 2 phases by exploiting any particular physical property which is different for the 2. So, suppose we have caught some particular signal which records the variations of any particular property of the system which is widely different for the 2 phases then from the continuous signal we would get an idea about the distribution of the 2 phases and from the average value we should get an idea regarding the incite composition of the 2 phase and this is usually done.

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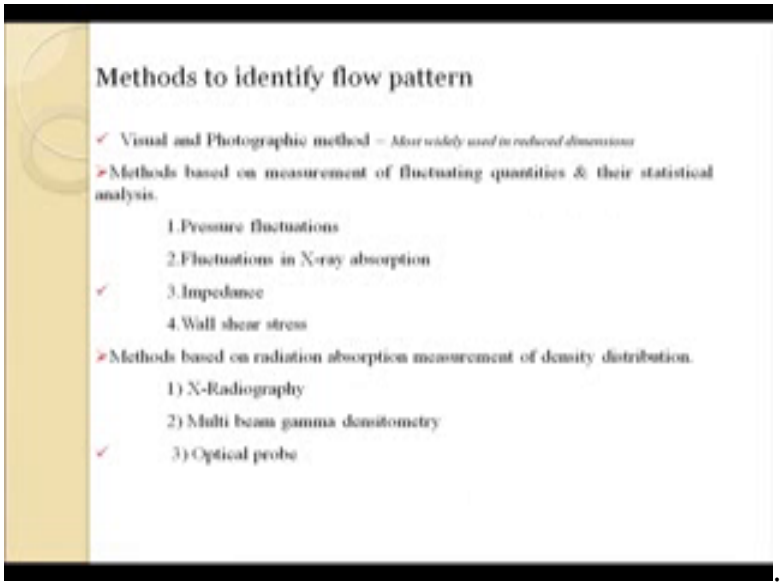

In fact, the most widely used technique as I have told you the visual and photographic method they actually operate on the difference in the transference of the optical property of the 2 phases and this is the method which is most widely used.

Now, for macro systems we find that large number of techniques as I already mentioned related to pressure fluctuations fluctuation in x-ray absorptions impedance wall shear stress probes etcetera can be used. But we find from the survey of the past literature that for reduced dimensions most of this techniques they do not work.

The primary reason being that most of the techniques are intrusive in nature and when they are intrusive in nature the macro systems it does not matter much because the flow passage possible will be quite large compare to the physical dimension of the probe which we are going to use, but to make probes of much smaller dimension as compared to the dimension of a micro channel is definitely difficult.

As a result we find that the most widely used technique in reduced dimension is visualization and photographic techniques.

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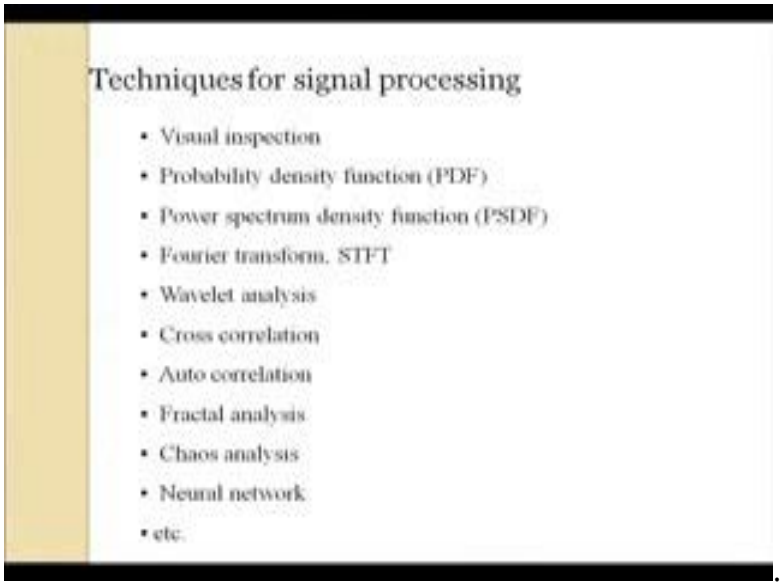

Firstly, it is not intrusive and the other thing is and secondly, it can just measure the variation of voids very easily and thirdly with the recent advancement of your electronics and very high quality camera coupled up with quite sophisticated image processing techniques now photographic techniques have become quite popular for micro skills systems.

Well apart from that also I wanted to mention one more thing regarding the other techniques pressure fluctuation or impedance probe etcetera there are 2 ways. 1 is we can just look at raw signal and we can try to understand that the distribution of the voice.

The other thing is to perform some sort of post processing of the random signals may be statistical analysis of the signals and then from the obtained from the statistical analysis we would be a better position to understand the flow distribution.

Now, usually the techniques which are applied a probability density function power spectrum density function and so on so forth all of this have been used with different levels of success for macros systems.

But for micro system to the best of my knowledge power spectrum and probability density function have been used the others have not been used much. In fact, apart from visualization as already I have mentioned other techniques also not have been used.

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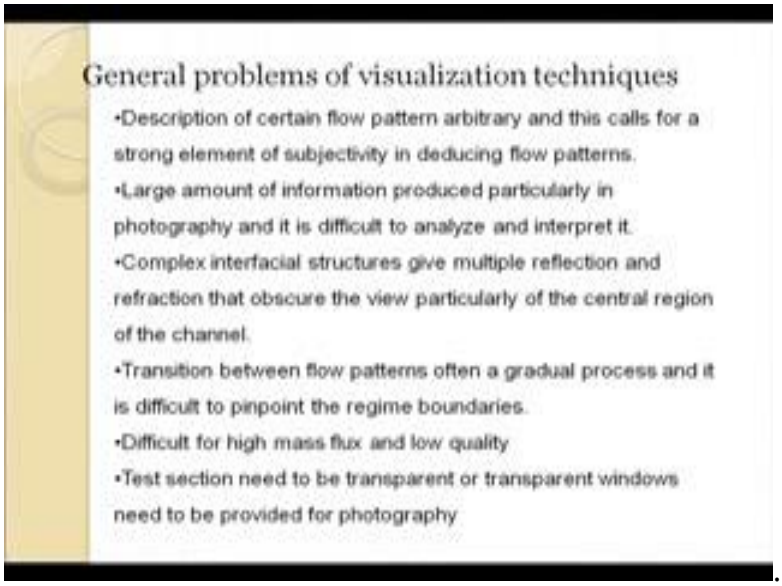

Now, for visualization if you are using definitely whenever, we use a particular technique there will be some problems and therefore, those problems have to be either minimized or they have to be eliminated.

Now, as per as visualization technique is concerned the first problem is that just by seeing that from with our naked eye or by seeing through by means of a camera lens it is very difficult to deduce the flow patterns. Because there is a large amount of subjectivity involved in estimation of flow patterns and particular if we are dealing with such small dimensions it is really very difficult even if you have a very powerful microscope to understand the distribution of the phases.

And we also have to remember for the most of the past researches have reported that there are large number of flow patterns occurring over the entire cross section possibly that explains that when slug flow plug flow occurs people sometimes report only liquid flow only gas flow only liquid plug flow and liquid ring flow and so on and so forth possible it is very difficult to identify that cross the flow distribution over the entire section.

And most of the thing we try to judge based on our particular qualitative analysis for example, suppose we see over a particular time frame only continuous gas core is moving and the liquid is as a film possibly we will be recording for say 30 seconds, 40 seconds and we classify it is annular flow.

Someone, who will be more carefully and will be recording for say 1 minute might see some particular bridging of the or necking of the continuous gas core and that person would identify this particular pattern as either slug annular or may slug ring flow etcetera.

Therefore, it all depends on the subjectivity or the accuracy with which or the rather the tenacity with which the experiments have been performed this is number 1 this is particularly quite serious in case of micro channels especially when we know that large number of flow patterns can exist at the same time and usually we record the probability of existence of the different patterns in order to construct the flow pattern map.

The other thing is usually we find in photography a large amount of information is produced and it is very difficult to analyze and interpret the information and more importantly we find that usually the interfacial structures are quite complex and in a micro channel the interfacial structures will be of comparable magnitude to the channel dimension and therefore, they give rise to multiple reflection refraction and this often obtuse the view of the central region of the channel.

Possibility we can an idea regarding the distribution of the outer periphery of the channel and it is very difficult to actually know what is happening in the inside of the channel. The other thing you have to remember is that for all particular 2 phase flow systems the transition is a gradual process, it does not happen (Refer Time: 10:34) at particular under one particular conditions. Therefore, quite naturally it is very difficult to pin point the regime boundaries.

And of course, we all know that it is definitely much more difficult for high mass flux and high and low quality systems that is obvious and the most obvious thing which we all know that if you really have to use this particular techniques the visualization and photographic techniques naturally the test section as to be transparent which may not always be possible.

In case, the test section is not transparent then we need to install transparent windows at intervals to enable visualization of the flow phenomenon occurring inside the pipe. Now, some of these can be eliminated for example, a very serious objection is this multiple reflection this is particularly true for the case of circular mini or micro channels.

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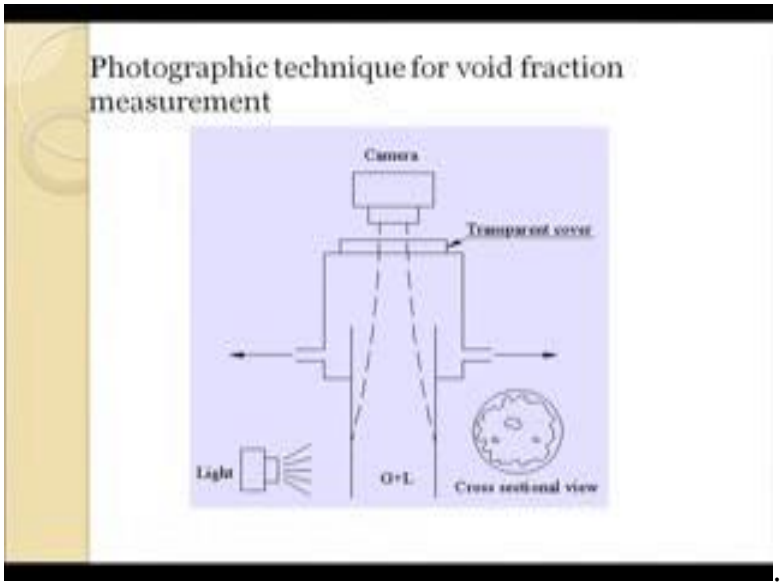

Now, for this we can often do 1 thing we can often use a view box is simply rectangular.

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Or a square box which is installed in the in the section which you want to view and this particular box is usually filled up with some particular material which as the same refractive index as the refractive index of the tube material refractive index same as tube material.

What this often does is it minimizes the refraction which occurs at the tube substance and

therefore, it possibly gives us a better representation of the flow inside. The other thing which we should remembering is that it is not sufficient to have a very high end camera for visualization studies the associated lighting is equally important in this particular case and very frequently we find that our success in determining flow distribution depends more on the lighting than on the camera.

Therefore, the lighting system is quite important and we have tried a few lighting systems just to see other its not only the lighting system it is the relative placement of the camera light etcetera it also depends upon the background that we are provided and in literature you will not find much information regarding this things, this are basically done by (Refer Time: 13:10) method.

And so therefore, it depends upon the fineness and (Refer Time: 13:14) sense of the observer or the experimented some particular lighting arrangement that we have shown which might be helpful in capturing the cross sectional average distribution of the words are shown here where we have the camera mounted on the top and the light from this side, but of course, we have all know that this things are much easily said and done that is true.

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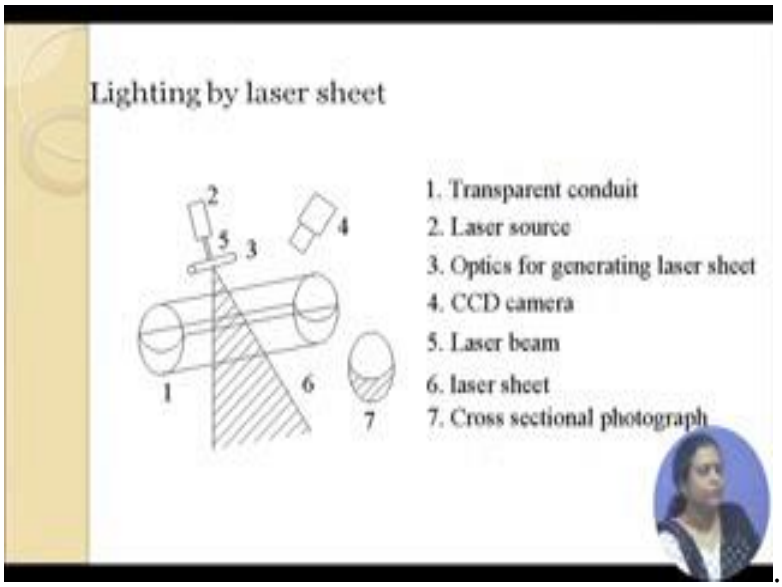

Well there is one more thing also to capture the cross section we can have we can generate a laser sheet as shown in the particular slide and this particular laser sheet enables its illuminates the cross section and gives us an idea regarding the cross section

distribution.

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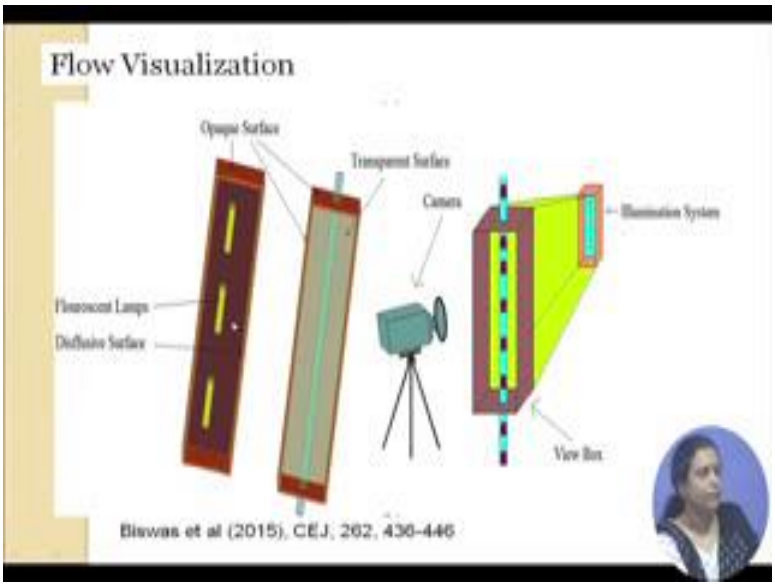

Now, as I was telling its very important to have the lighting arrangements and very frequently particularly if we are very interested or if we have to do image processing it is very important that the lighting is propolita and the view box is placed.

Now here I have put up one particular arrangement which has been tried in the multiphase laboratory first studying liquid flows through a 2 millimeter diameter conduit as you can see what we have done we have put a view box which is transparent at the back and the front and the other edges are covered by a opic cover.

And we have an elimination system which is of the same dimension as the view window that we want to see and this has a back lightings arrangements. So, that it illuminates the test section from the back and the camera is position in the front.

Now, just taking photographs and observing from there is definitely one particular way of understanding the flow distribution, but more important than this is the image processing technique.

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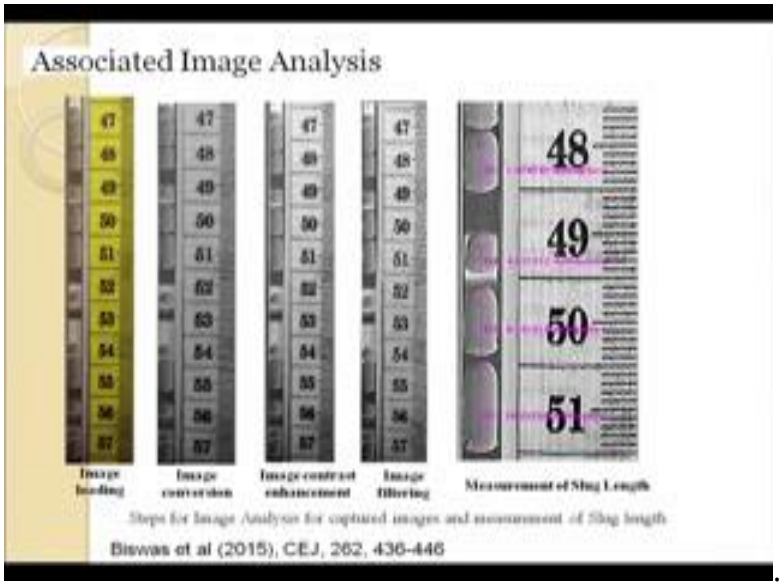

Therefore, it is along with recording the signals sorry recording the images a proper image analysis is necessary keeping in view that the flow pattern is predominantly slug in this particular case. Now, I have just given a representative example of the different steps which are involved in image analysis we can use different software, but more or less the same type of steps will be involved quite naturally we have an image naturally what we have to do first we have to load the image in RGB format and then we have to convert all the image into the grayscale mode.

Once you have convert it into grayscale mode it enhances the contrast of the images and once the contrast enhancement is done we have also do one more thing for enhancing the contrast if we can subtract the back ground image from the continuous flow image. And definitely, just like all devices filter should be involved to remove to reduce the image noise and after that definitely there should be some sort of calibration with the help of which we would be able to determine that the individuals slug parameters namely the slug length, the slug frequency and the slug velocity.

Therefore, visualization techniques it is not only important that we have a good camera it is equally important that you have a very good arrangement regarding the associated optics the lighting arrangement and you have a very good software for the processing of different images.

Now, from this it is quite obvious that well all though this particular technique the

visualization technique or the photographic technique is widely used, but as we have seen that it has got its own set of problems all though they have been minimize to some extent with the advancement of technology, but people have always be searching for more objective methods of identifying flow patterns.

Now, as I already I have mentioned there are really a large number of objective techniques in macro systems, but most of them be intrusive cannot be used for micro systems. One of the non intrusive techniques which can be be used is based on the absorption and attenuation as well as scattering of light or any other type of radiation where the absorption or the attenuation coefficient is different for the 2 phases.

Now, one such device has been developed in the multi phase flow laboratory of IT Kharagpur it is an optical probe technique we have used it for many and micro systems and in literature there are researches you have used an identical technique for micro systems as well.

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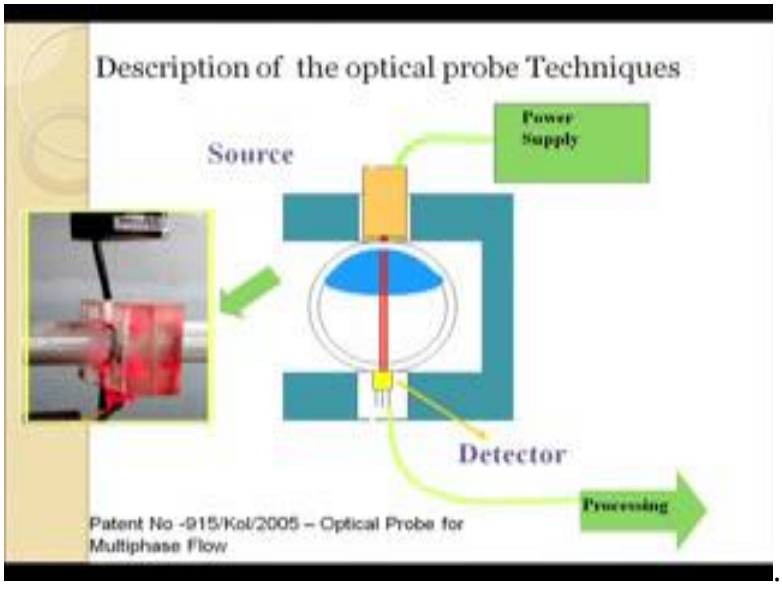

Now, let us see how it works it is a very simple system what does it have it has got a laser source at one end this is the set up which is there in your lab and it has also been patented.

We have a source here and we have a detector just on the opposite side the source it is a more or less or narrow source or other it is a pointed source which sends a point average

rather if it send a small amount of light through the laser beam through the test section.

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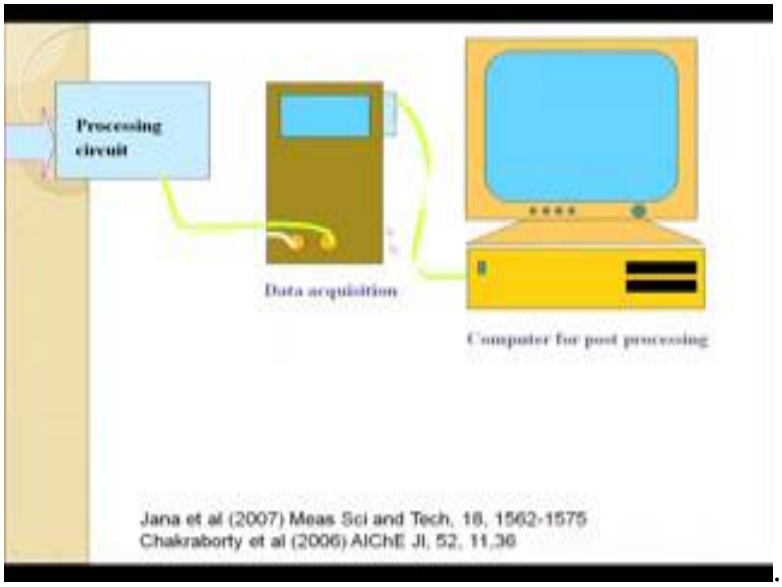

And there is a photo diode sensor at the top this photo diode sensor when it receives light it converts it into a voltage signal and then this voltage signal is send to a processing circuit for further processing and data acquisition and then it gives us a continuous voltage time signal on the computer screen by means of each we can understand flow distribution.

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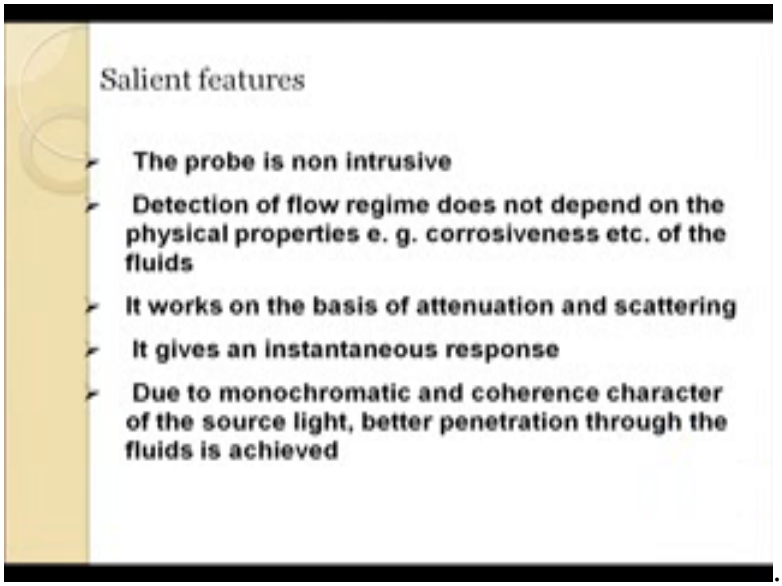

Now, the some of the salient features of the probe which explains it is versatility or popularity is firstly, it is non intrusive secondly, the detection of the flow regime does not depend upon the physical properties like corrosiveness of the fluids.

So that it can be used for any toxic hazards any sort of fluid not only that it does not disturb the flow passage more importantly it is not affected by the corrosiveness of the fluid and there is very there is no fluid loss by sticking to the probe etcetera.

The way is it works on the basis of attenuation and absorption ok, or it works on the basis of attenuation and scattering of light what it does is that when light is passing depending upon the composition of the 2 phase medium light it is absorbed by the medium if the medium has a higher proportion of more absorbing substance then naturally it will be absorbed more if it has larger proportion of lower absorbing substance then it is absorbed less.

Along, with that depending upon the presence of bubble, droplets, interfaces etcetera the light it may be scattered as well. Therefore, it has a 2 way purpose. Firstly, it detects the flow distribution not only by rather it detects the distribution by scattering of light it also gives us an idea regarding the average proportion of the 2 phases based on the average signal which depends upon the attenuation of light.

More important it gives an instance response and due to the monochromatic and coherence character of the light a better penetration through the fluids is achieved.

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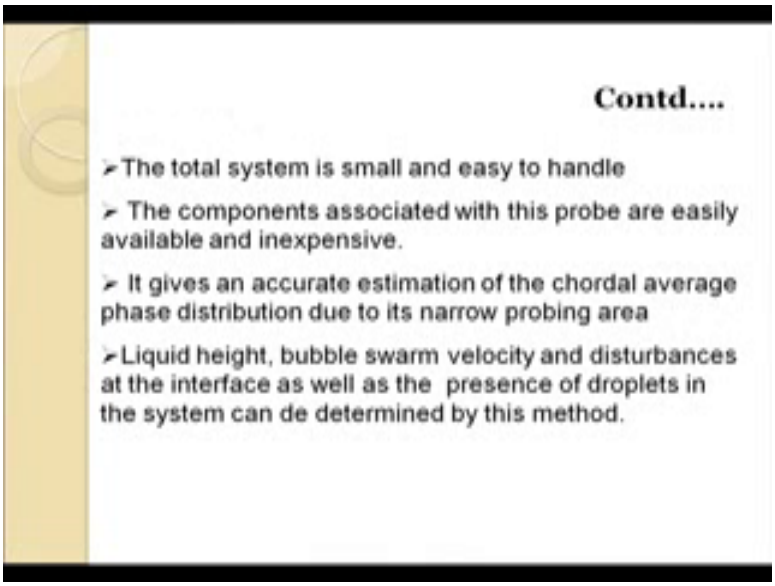

And well the total system is easy to handle and it is small the components associated are available and the inexpensive it gives us an accurate estimation of the chordal average phase distribution and apart from your flow distribution it will also give us a large number of other measurement of large number of other parameters for example, bubbles swarm velocity and disturbances at the interface when the interface disturbance are more naturally at that time we get a more VV signal when the interfaces move we get a much more smooth signal as expected.

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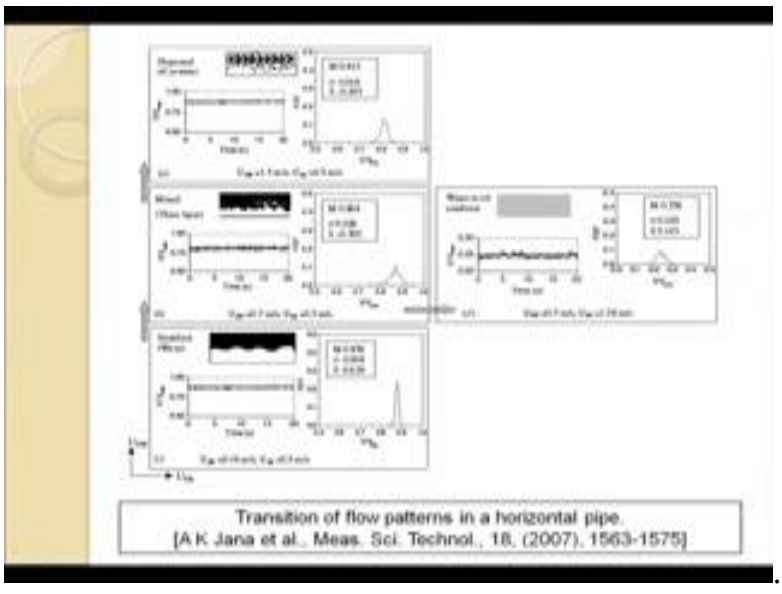

Now, in this particular slide we will been it is very we will be seen how it gives us the idea regarding the distribution of the 2 phases in a macro system what if we observe here what do we find we find that for stratified this system say what do we have one particular signal at a more or less high velocity, high voltage right.

What does it show since this signal they were recorded with kerosene and water? Therefore, kerosene absorbs more than water. Therefore, the signal will be higher than greater amount of light is transmitted or in other words when there is a greater proportion of water in the test passage.

Therefore, with absorbing the mean of the signal we find that more or less a greater proportion of water is associated and we find that if we take a time average histogram of the signal which is nothing, but the probability density function and rather it is the PDF of the signal I will be just touching upon a little more details of the PDF after a short while.

If we take a time average histogram of the distribution of the words then what do you see? It has a very less spread, which shows that more or less water present in a larger proportion, but the interface between the 2 is more or less moved.

On the contrary if we go to the mixed or the 3 layer flow pattern if we remember that we are discussed for liquid flows then we find that the signal is much more wavy just from the visual appearance of the signal it is not very evident, but if we take up the time average histogram of the distribution of the 2 phases we instantly we can understand the difference between the 2.

And we observe that in this case signal is much more spread out although the mean is not very different now as we go to may be stay still higher water velocity and we get a completely dispersed flow pattern we find that the spread has reduced.

And while the mean value is not very different when the mean value is not very different we know that predominantly water is the continuous phase and from the spread we can understand whether the interface is smooth or whether it is wavy it is quite natural that with a presence of droplets or bubbles or very wavy interface the spread will become larger.

Just from the visual appearance of the probability density functions we can note that the these 2 they refer to a dispersed distribution while this refers to a separated flow pattern now if we compare the 2 or rather if we compare dispersed oil in water and water in oil see just by visual appearance it would be very difficult to differentiate the 2.

Even by looking at the 2 signals immediately the first thing it strikes us is the difference in the mean value. So that itself tells that if water was the continuous phase here oil will big a continuous phase here number one and if you compare the spreads if you find the spreads and not very different which suggest that both of them refer to disperse pattern with water continuous here and oil continuous here.

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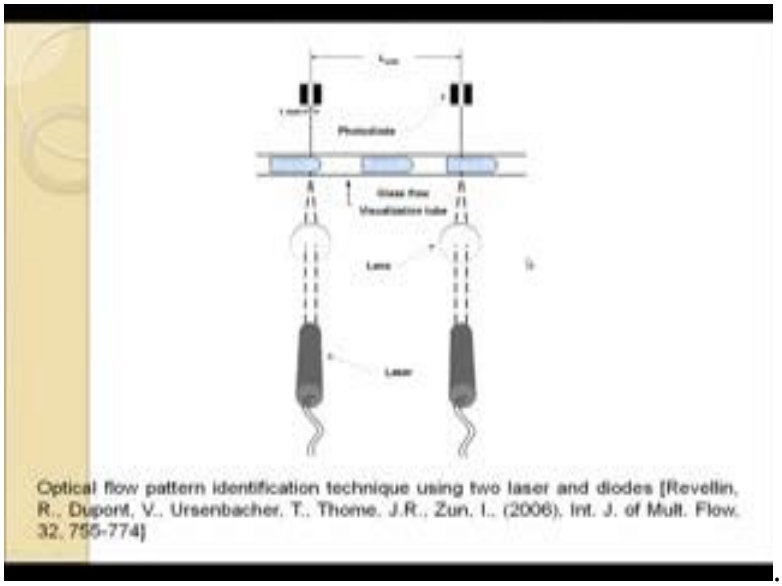

Now, this particular thing or this particular device was also adopted and it has been used with quite a good amount of success in literature and we will be discussing about this in our next lecture.

Thank you very much.