Multiphase Flow
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Lecture No. 40
Measurement Techniques for Two Phase Flow Parameters - Estimation of Flow Patterns

Well, so today we have come to the end of this particular video and you will be having your last class today. So, today we will be discussing the measurement of two phase parameters; the last parameter, which I thought was important for discussion was the estimation of flow patterns.

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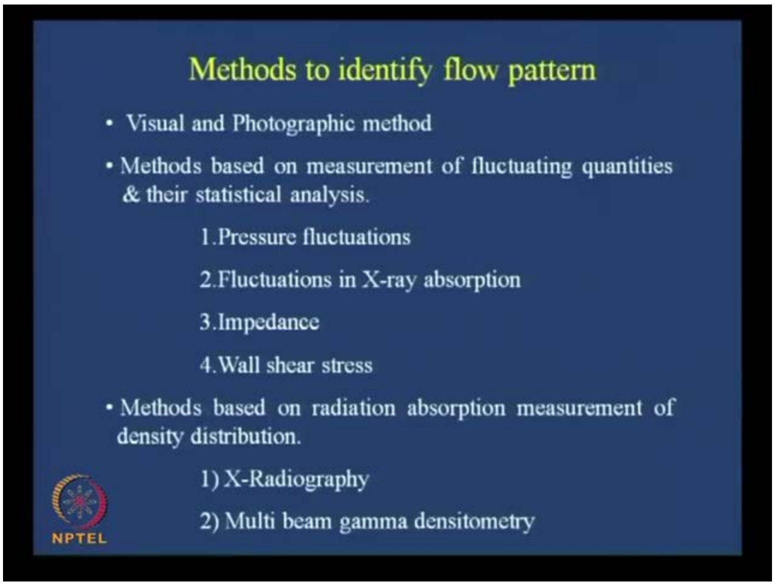

So therefore, what I was thinking initially we had discussed, initially we had discussed the different techniques to measure the pressure drop, and we found out that for measuring pressure drop, we have we do it for any particular fluid flow problem b it is single phase flow or a two phase flow or whatever it is, but what are the extra challenges in measuring pressuring drop in two phase flow situations; this was number one. After that, the next thing, the estimation of void fraction, which you do not need in single phase field.

It is a unique parameter which you need to know for any analysis of two phase flow or multiphase flow situations. And so after that apart from the void fraction, the insitive composition in next things which you also know need to know is the insitive distribution of the two phases. It is not always sufficient to know that what is how much proportion of the two phases are there, but it is equally important to know in what ways the two particular phases or the more than one phases, how they are distributed.

Because depending upon the distribution their interfacial area of contact and all other dynamic parameters they are going to vary. So therefore, first we discussed the insitive composition; how to estimate it now, we will discuss the insitive flow distribution or the phase distribution how to analyze it. Now, it is very evident you can very well understand that it will appear to you that measuring the insitive composition is a greater challenge, because you have to get something quantitative out of the measurements, but in this case, it is a qualitative description of the way the two phases are distributed.

So, definitely whatever techniques we had discussed for measuring or for estimating the void fraction should be applicable for measuring the flow pattern estimation also rather for estimating the flow patterns. The first technique which comes to our mind is naturally simply visualization, if it is the two phase flow the two phases they are transparent and they are the flow is occurring through a transparent channel, then the best thing to do is to just watch it and find it out this is how the this is the primary technique. If you use other techniques also it has to be calibrated with the visualization techniques.

Principally, just the same thing that I had mentioned in your void fraction measurement here the same principle applies, we shall be exploiting any particular physical property which is widely different for the two fluids, it can be difference in density, it can be difference in electrical conductivity, it can be difference in the absorption coefficients, it can be any particular sort of a physical property, which is widely different for the two phases. So, observing the variation of that particular physical property, we shall estimate how the two phases are distributed. So, just in a nut shell the thing is I will not going into the details of the techniques, which you have already discussed in the void fraction estimation certain other things I would like to discuss.

For example, the natural techniques or the techniques which at once comes to your mind is definitely, first is the visual technique and associated with the visual technique are the photographic methods naturally, you cannot say that I have observed it visually definitely we can draw schematic of it, but for a for the outside world, it will be much more convincing. If you can take out some photographs and show it now this is a very reliable technique, because the most reliable thing naturally is our own eye is it not? But definitely it also has it is it is own disadvantages as I have written it down. In this particular slide I have just, I have just written down that the basic problems, which all of us know.

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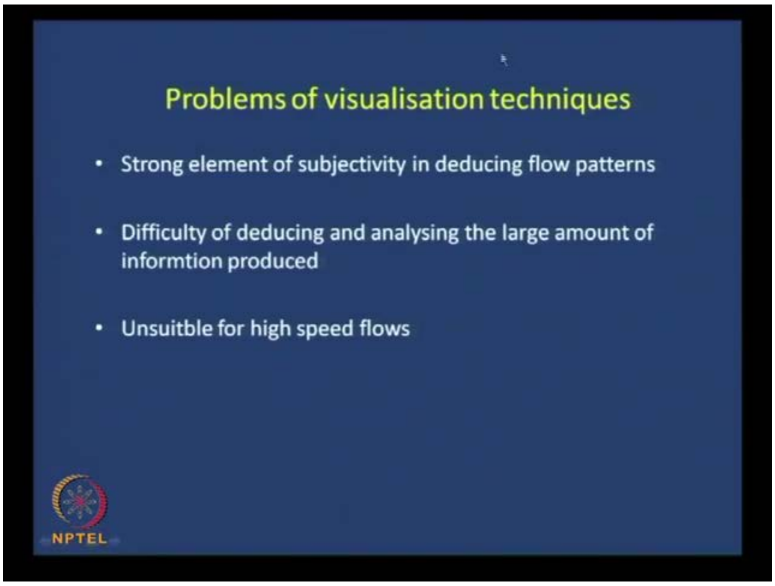

The first thing is that if the flow is occurring generally, we will find they are occurred at very high speeds when they occur at such high speeds, it is very difficult to distinguish between the two phases particularly for annular flow for dispersed bubbly flow, you will just find something is moving through the passage. It is very difficult to apprehend whether it is a bubbling mixture moving or whether, it is gas core wet in rain droplets and your liquid film moving it is very difficult to differentiate.

The other thing is usually what happens, what particularly for photographic techniques what we find there is a series of reflection and refraction through the curved walls and through the interfaces therefore, very frequently we can just see what is happening near the walls what is happening inside the channel, it is very difficult for us to find out by using photographic techniques, this is the second thing the third thing is suppose you have a large number of information, it is very difficult to analyze such a large amount of information.

So these are the basic problems of visualization techniques, which include your visual observations as well as your photographic techniques. The photographic techniques might include high speed photography, high speed cinematography, high speed videography and so on and so forth depending upon how much information and what information you have you want to get out of these observations. This is number one definitely when you have a transparent test section, transparent fluids or in even in an opaque is container or any a opaque pipe, if you have some transparent windows you can use this.

Apart from that just as I had mentioned in the while I was discussing the void fraction measurement definitely, there can be absorption of x rays the amount of x rays which will be absorbed that will give you some idea of more or less the distribution isn't it. So, x ray absorption multi beam gamma density symmetry as I have written down this is one particular technique.

The other things which are impedance technique is definitely, one difference in electrical conductivity. What happens? Suppose liquid is flowing it has got a high conductivity moment, suppose a bubble comes and touches the electrical probe definitely the conductivity instantaneously falls. I have got certain pictures I believe to show you these particular things.

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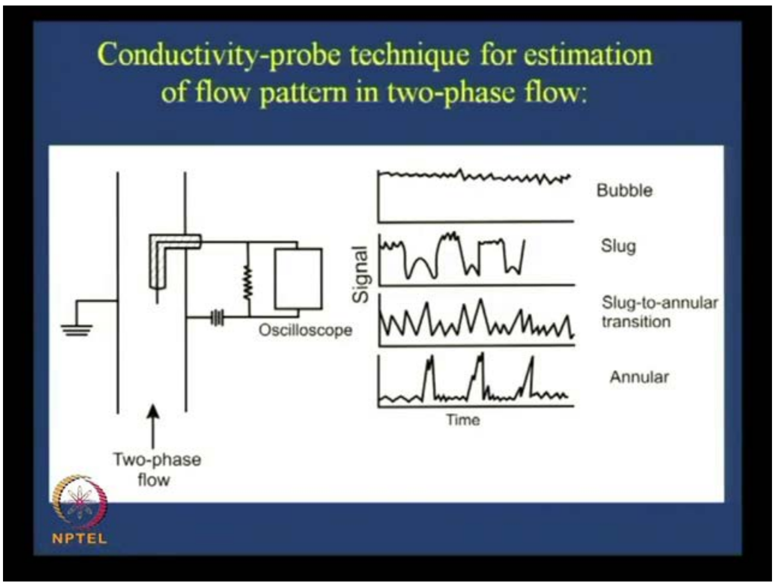

So, in this particular case, you will understand how this conductivity probe technique works. Here, we are working on the basis of a point electrode probe, where we measure the voltage difference between one particular electrode, which is fresh mounted with the walls another electrode a point electrode, where the tip is only conducting. Now, what happens, when only water flows through this then definitely, we have a high voltage across this. Basically the current which flow that is passed through a resistance and the voltage across the resistor that is recorded as a function of time that is either recorded in oscilloscope or in a pc or whatever it is.

So therefore, what we find that only when water is flowing, we have a high voltage; only when air is flowing, we have a very low voltage output. Now, suppose bubbly flow is there. So, we have a large amount of water here small, small bubbles will come they will strike the probe periodically, moment that happens, moment the bubble comes and strike we have some sort of fluctuations in the high voltage signal better than this signal actually, the things which we get here if I draw it and show you it is just if I draw it you can see the thing, I will just draw it down.

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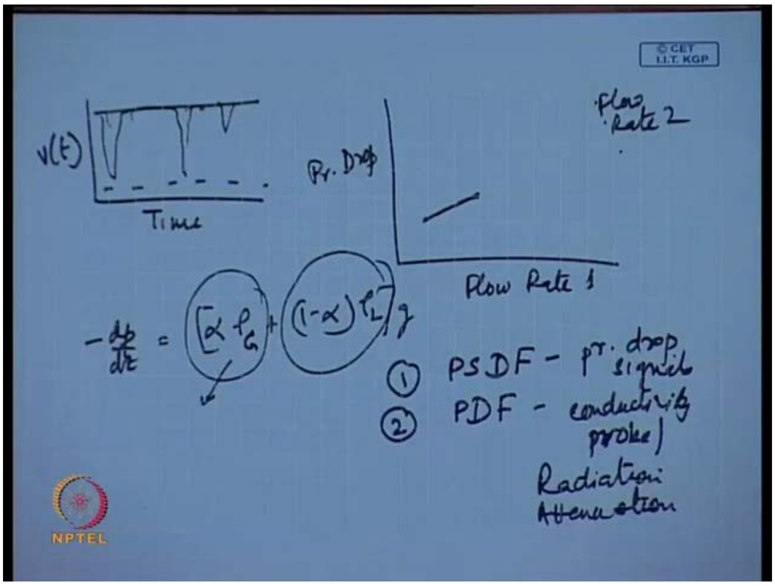

Therefore, if you see you find that only when air is water is there, you get a high voltage; only with air you get a low voltage. When there is a bubbly flow usually, what happens? You get such sort of spikes. Now thing is if it is dispersed bubbly flow, then it is dispersion of bubbles, then naturally this signal is going to be very wavy just like I have shown in the slide. And if there are few bubbles coming and striking, then you will get some such spikes and other wise a more or less continuous output.

Now, when we have slug flow; this is for a vertical pipe I am showing, if we have slug flow then in that case what happens at some particular point, the Taylor bubble comes and hits it. When the Taylor bubble comes the conductivity falls instantaneously and as long as the Taylor bubble moves the conductivity is almost at 0 moment, the Taylor bubble goes away liquid slug comes suddenly your voltage it raises up again, when Taylor bubble comes it falls down.

So therefore, you can see this particular periodic phenomenon is very well captured by the conductivity probe signals by its alternate peaks and valleys as it is shown remember one thing, this is a true signal. So, that is why we actually we should have got some square wave sort of a thing isn't it should have been square wave, but the thing is first there is a liquid film here and there are other oscillations. So, naturally therefore, you get some such sort of spikes and the due to certain aerations in the liquid slug, you get such oscillating signals in the liquid slug region.

Now, we keep on increasing the air flow rate what happens. The Taylor bubbles they become larger, larger more irregular they almost occupy the entire cross section and what do you find initially? The average voltage was at high voltage then it was periodic here, if you notice actually the average voltage has fallen down and there are spikes showing that occasional passages of liquid junks, irregular liquid masses and you can very well understand the chaotic nature of the junk flow patterns from this particular signal isn't it is totally an erratic signal.

And when you get annular flow it is almost pure gas flowing. So, you get an almost zero voltage signal here where the few spikes, which occur when liquid droplets come and strike the probe is it clear to you. So, if you observe you will find more or less bubbly flow is just the mirror image of the annular flow pattern. Usually, this is for disperse bubbly flow, but for actual bubbly flow you just get the mirror image of annular flow and the slug flow pattern, it is almost as if it is alternating between the bubbly flow pattern and the annular flow patterns. Sometimes, it resembles bubbly flow sometimes annular flow again bubbly again annular in that way, it goes on and junk flow is a totally erratic situation.

So, simply by observing the signals you find that more or less you can get an idea about the type of flow pattern, which is being distributed I have shown this for a vertical pipe in horizontal pipe. What extra you have stratified flow, stratified smooth flows, stratified wavy flow therefore, we will be discussing by a proper design of this (()) probe we can actually differentiate between the different flow patterns.

Where the problem arises, problem at firstly the first thing is it is an its cheap its instantaneous response therefore, moment the bubble touches there is a drop in the voltage again, when water touches again there is a raise in voltage. So, in the response is instantaneous this is one good thing about the conductivity probe technique, it is simple hazard free all those advantages are of course there.

But the thing is that, the first thing is we need a very good design of the probe in order to identify all the different flow patterns particularly, where the problem arises at the transitions, say it is bubbly struck transitions under that condition it is very difficult for us to differentiate between this periodic things and if you have a large number of spikes here, then it is then sometimes it becomes very difficult to differentiate between wispy annular flows and bubbly flows. So, but if we use a proper differentiation technique or rather see, if its defined or thresholds very correctly then identification of flow patterns by the conductivity probe technique is not very difficult.

There is another technique that the thing which we do is by measurement of the pressure drop signals. Now, that is number of things that we can measure first thing is we can simply measure the pressure drop as a function of velocity, we keep on increasing one velocity keeping the other constant and then we measure the, if the pressure drops under different circumstances after that suppose, we plot say pressure drop or the pressure gradient whatever, it is as a function of one particular flow rate.

Flow rate of phase one keeping the other constant flow rate of phase two is say I will, I will show you graphs which you have generated in our own laboratories regarding this then, we will find that definitely as flow rate increases there will be an increase in the pressure gradient or the pressure drop, But the curve will not be a continuous curve throughout it will have different slop in different flow patterns for example, I have got one such example, see if you observe this particular slide, you will find that we have obtained different slops for different flow patterns.

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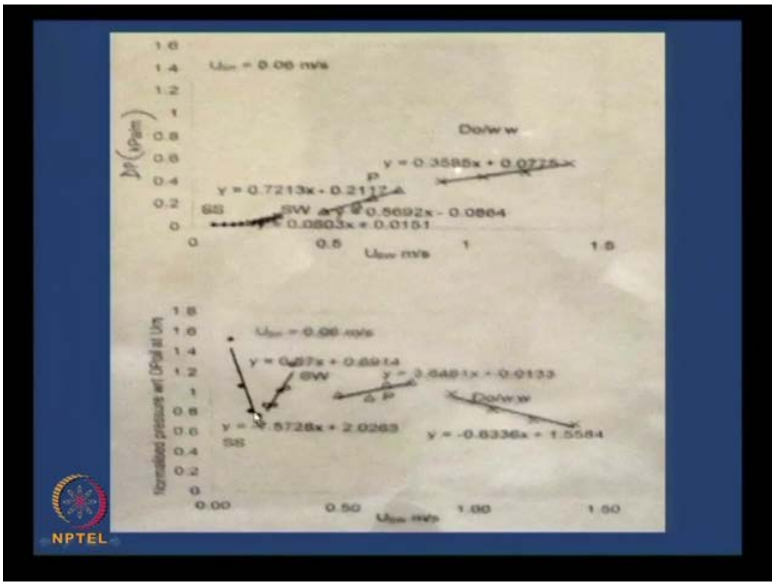

This is first stratified smooth; this was for liquid liquid flows that we have got it. In liquid liquid flow we could not use the conductivity probe technique. Why? Liquid was sticking to it; and then a lot of problems were there. So, under that condition, we use the pressure gradient or the pressure drop technique, we found that particularly, here if you observe this is the stratified smooth pressure gradient, and then this is a stratified wavy then, this is the plug this is the disperse for we got quite different your slops are quite different curves for different flow patterns. So, this could give you rough estimate of the flow pattern, but this is not a very good technique.

A better technique will be if you if we can record continuously record the pressure fluctuations with time, just like we have recorded the variation of effective conductivity with time, same way if we can record the pressure fluctuations with time then probably we get a better technique. There is one other technique, which we can use for vertical flows that is suppose for vertical flow usually we know the gravitational pressure gradient is the most important.

So, if we write down the expression for the vertical pressure that is the pressure gradient under vertical flow conditions, more or less it is alpha rho g plus 1 minus alpha rho L is it not? So you into g. Therefore, what we find is when we have bubbly flow naturally this term becomes important and when we have annular flow, this term becomes important. So therefore, when we find that the pressure gradient it is close to this, we can tell its annular flow, when we find the pressure gradient is close to this, we call it we say its bubbly flow and once intermediate, we say its slug flow. This is a very crude technique, but this can be used further a rough estimation.

The best thing is to record the pressure fluctuations, if by using a transducer we can convert the pressure signal into an electrical signal and we can continuously record the electrical signal then probably, we get a better estimate of flow pattern, but from that also we have found that the variation of pressure signal or the pressure it is the variation of pressure at a particular point with time this is not a very, very reliable method.

So, in order to get useful information from these random signals often, we use some statistical techniques. Whenever see we have some random signals we cannot extract useful information say for example, from the pressure signal we are not able to identify flow patterns from the conductivity probe signals, we are able to identify the flow patterns very, very correctly. If we perform some statistical or any particular analysis of these random signals, then we will get more useful information.

Probably, I will not have time to discuss in detail the statistical analysis, but if you go through my web course you will find that the discussions are there on two particular commonly used statistical techniques, they are the first technique is the power spectral density function analysis and the second technique is the probability density function analysis.

Now, I will not be going into the details of this power spectral density function analysis and the probability density function analysis, this I leave as a self study which you will getting handouts and it is also available in my web course. I will just show you what are the usually we perform the power spectral density function analysis for pressure drop signal and this PDF analysis this is performed for your conductivity probe technique or your radiation attenuation techniques for these particular things they are used.

We can use other techniques as well, but these are the commonly used methods. When we have to go for non conventional flow geometry or non conventional fluid sphere something then, we go for other techniques. If time permits, I will just tell you very briefly regarding the PSDF and the PDF technique, but otherwise this is left as a self study for you.

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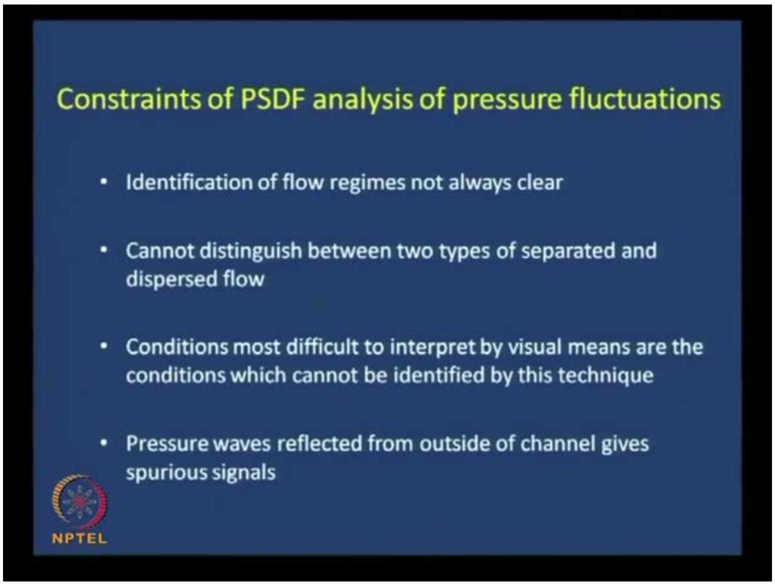

Now, the only thing which I would like to show you is that if you perform the PSDF technique, what we usually find suppose we perform the that particular technique and then we find that for the pressure drop. If we analyze the pressure drop signals usually we get output something of this sort this is the PSDF analysis as a function of frequency with frequency.

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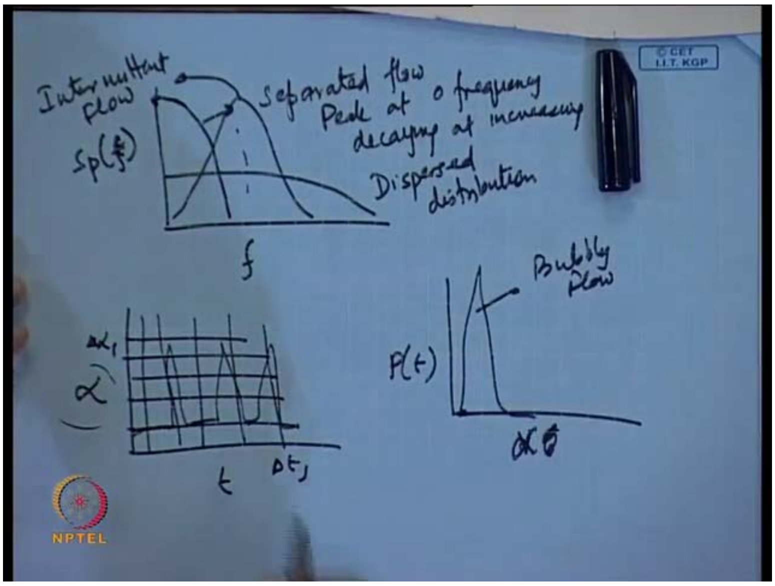

Now, when we have a stratified flow distribution or we have a separated flow distribution usually, we have a peak at 0 frequency and then we have something of this sort and when we have a dispersed distribution, it is something of this sort usually if you perform PSDF for pressure drop analysis for any particular disperse distribution, we have almost a uniform frequency for all particular cases. So, it gives you a flat curve like this and for any particular separated flow distribution, any particular separated flow you get a peak at f equal to 0 and that decays at increasing frequency.

For separated flow you get this you get a peak at zero frequency and this the case rapidly decaying at increasing f and when we have slug flow, then what we have we find that this separated flow peak it shifts to some higher value of frequency, we have something of this sort this is for intermittent flow this is usually what we get therefore, if we get a peak something of this we know definitely, it is a separated flow pattern. If it is vertical flow we can definitely say it is nothing, but annular flow, but if it is horizontal flow we cannot say whether, it is stratified or whether it is annular we just know that it is separated flow.

If we get something of this sort, we know it is disperse pattern. If it is a gas liquid system then fine it will be bubbly flow because we will always get gas dispersed in liquid, but if it is a liquid liquid flow we do not know whether, it is oil in water dispersion or water in oil dispersion that problem is there. And for intermittent flow pattern that means something is coming and going again its coming and going for example, the slug flow pattern we find that this peak is shifted to some particular frequency, which gives you the frequency of passage of the Taylor bubbles. So, this basically gives you the frequency of passage of the Taylor bubbles the shift of the frequency.

So, more or less if you get these particular PSDF you are in a position to tell that which particular flow pattern we are going to encounter, but unfortunately under normal circumstances we find that we rarely get such well defined PSDF actually the PSDF which we get are something that I have shown in this particular slide.

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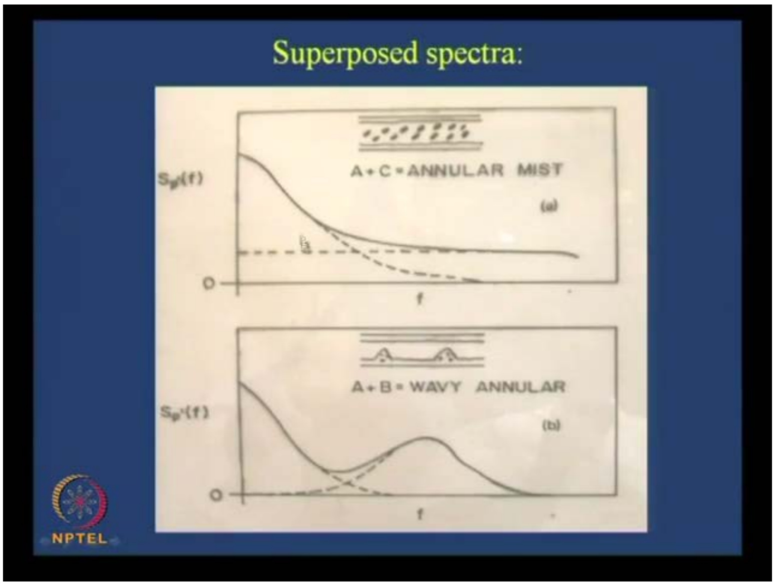

Usually, we never get something which is here and which is decaying down we get, we get usually we get a PSDF which has a peak at zero frequency showing that it is a separated flow pattern and then it does not decay rapidly to zero at higher frequency, it then takes up or performs something of the dispersed flow, flow pattern.

Why? Because obviously almost never get pure annular flow there are droplets isn't it in the gas core therefore, it has some characteristics which show that it combines the characteristics of annular flow pattern as well as the dispersed flow pattern, which is the actual physical appearance of the annular flow pattern in industries or we may get something of this sort, when it is wavy annular depending upon the frequency of the waves we get a peak here and since it is separated we get something of this sort.

So, from these type of super imposed or super imposed PSDF we very frequently do not get useful information, the constraints of the PSDF therefore, pressure fluctuation or analysis of pressure fluctuations or recording. The transient variation of pressure with time it is not always very useful, first is the raw signals do not give us much we have to perform some statistical analysis usually, for pressure signals we perform the PSDF analysis. The problems of PSDF analysis as I have already said the first problem I have written down here identification of flow regimes is not always clear because we usually get a super imposition of spectra, we do not get a well defined spectra under ordinary circumstances.

What is the next thing it cannot distinguish between the two types of separated flow, it cannot distinguish between the two types of dispersed flow, this we have already discussed other thing is see the thing is its we can very well distinguish between annular flow, bubbly flow, slug flow under ordinary circumstances only when we have very high flow rates or fluctuating flow its difficult under such conditions PSDF also does not give us a proper estimation of flow pattern.

So, therefore, conditions which are I have written it down in this particular form conditions, which are most difficult to interpret by visual means are the conditions, which cannot be identified by this techniques therefore, sometimes it becomes very there is no point in using this technique and the other thing is there can be vibrations. In the test rate when flow patterns, flow rates are occurring under such high conditions there is a plump, there is so many things vibrations with the these vibrations can also be recorded and we will mistake them as fluctuations and pressure signal so, these are the problems.

So, in short the techniques are first in visual techniques definitely we will use them for calibration, but we cannot use them for high flow rates non transparent sections and so on and so forth in transparent sections also as I have told you photography does not give us a good estimate particularly, we due to the multiple reflection. Refraction at the wall this is number one next is pressure the common techniques pressure pressure drop measurements, pressure fluctuation measurements, the problems have already mentioned pressure drop measurement is definitely not very accurate, it just gives us a rough estimate of say bubbly is occurring here slug is occurring here.

But suppose I would like to find out what will happen at any particular flow rate, combination directly from the pressure drop measurements. It is not always possible it just gives us the trend of radiation of flow pattern nothing else. And if the other thing is radiation absorption techniques, it has its own problems regarding the handling of radiation etcetera, etcetera, which we had already discussed in your void fraction measurement things in great details, we had discussed so I will not be going into the details anymore.

The last technique which is the most commonly used techniques is the impedance technique, which is based either on the conductivity difference between the two fluids or on the capacitance difference between the two phase. Now, usually when we record any particular random signals, it can be pressure drop or fluctuations, it can be fluctuations in conductivity, it can be fluctuations in the amount of radiations which is absorbed by the two phase mixture. Whenever, we have we record any such fluctuating signal in order to get useful information as I have said we need to perform some analysis PSDF and PDF are the most basic analysis.

There are much better analysis Secants analysis, Wavelet analysis and so on and so forth, they are being used in all this, but the most two basic analysis are PSDF and PDF. PSDF and PDF the mathematical portion I will not be going into the details of it, the only thing which I would like to tell you is that as I was telling you the PSDF, it just gives you an idea regarding the fluctuations in the frequency and PDF the probability density function analysis, it just tells us that the probability that the void fraction will lie in any particular range.

So, for that what we do we divide the entire suppose we are plotting alpha verses time, this alpha can be obtained from conductivity measurements, it can be obtained from radiation absorption measurement, it can be obtained from anything. Now, if we divide the entire alpha into a large number of delta alpha, the division same way we divide time into a large number of delta t divisions this may be we have we are, we have divided into say delta alpha i number of divisions and delta t j number of divisions now, when it is bubbly flow. What is the probability of finding when it is will we find alpha? The maximum number of times at low void fraction isn’t it, isn’t it because most of the time it is it is only water very rarely will bubbles comes and strike.

So, therefore, this particular if see plot alpha verses time most of the time we will find the signal at low alpha and sometimes, it will be varying in this particular way so for most of the time alpha will lie in the low voided region. So, the probability of finding alpha at the low voided value is much higher as compared to the probability of finding alpha at the higher void fractions.

So, if we plot this particular probability as a function of say alpha usually, we use void fraction which is plotted as a function of alpha then, what we find the probability will be high at low alpha, when it is bubbly flow you agree with me therefore, we will get a peak something of this sort which denotes your bubbly flow. Did you get this point or do you want me to repeat this part it is clear to you, the thing is what we, do we get a signals.

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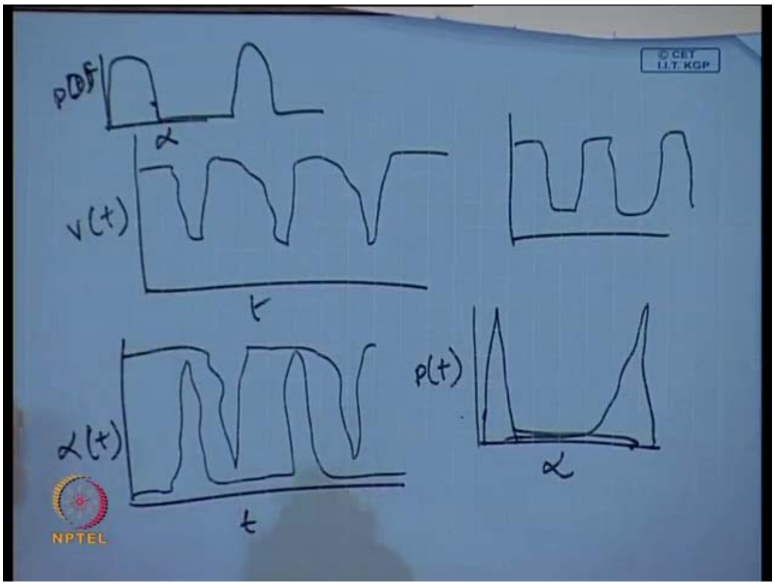

Suppose, we get any particular voltage verses time signal, we get something of something of this sort I will not put voltage, I will put alpha verses time that will be alpha as a function of time with alpha. So, therefore, we get some sort of a signal in this particular situation say we will get something of something of this sort we get. Now, whatever signal we can get now, if we find we will find that the probability of finding alpha in the low voltage region or low alpha region is high in this particular case. Alpha or rather we get more alpha value in the low alpha region as compared to high alpha region.

So, if we take the probability density function of or rather we perform the PDF analysis of this particular signal, what we will, we will get a high since the PDF will be high at low alpha, we will get a peak at low alpha and then we will get, we will get a very low sort of a thing at high alpha is it not? So, if you plot probability verses alpha is it clear to you therefore, when we get or rather the probability of finding alpha at lower voided values is high only when, there is or rather the probe comes primarily in contact with your water phase therefore, this shows bubbly flow for annular flow. What happens?

Annular flow this signal is something of this sort is it not? Therefore, the probability of finding alpha is more in the high voided region. Therefore, if we plot annular flow we will get some PDF something of this sort agreed and for slug flow. What do you expect slug flow is, simply some it will be something of this sort. So, here if you take the probability density function then, we will find the probability density function PDF verses alpha.

If we plot we will get one particular void peak here we will get one particular peak here. So, this gives us a very objective way of finding out rather identifying the flow patterns the mathematical details, I will not go, because I am running short of time in my web course you are going to find it. You are suppose, to go through it and understand the mathematical analysis, but remember we perform statistical analysis for a better appraisal of the flow situation for a more objective identification of the flow patterns.

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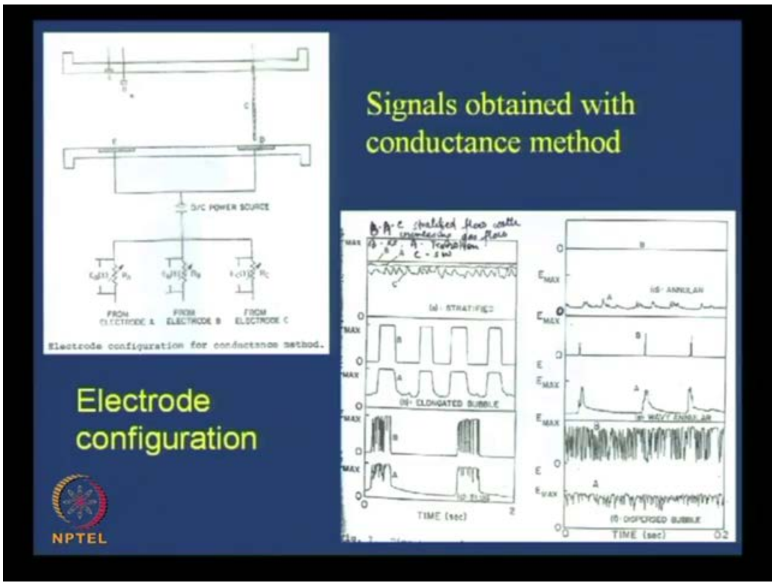

Now, just before end I would like to mention one particular interesting thing. The thing is suppose, we have used the conductivity probe technique for identifying flow patterns we get different signals, the conductivity probe technique. What it does? It measures the effective conductivity of the particular flowing mixture, when the effective conductivity is high we know it is predominant to liquid, when it is low we know it is predominantly gas well it is very fluctuating, we know that lot of interfaces it must be interact must be coming across lot of interfaces on other words it must be a disperse sort of a thing.

When you find that it is not much fluctuating then, we know that well lot of interactions it there are not lot of interfaces, which are there. So, it might be separated sort of a situation isn’t it. So, in this particular way we can identify or we can differentiate between the flow patterns which occur under different flow situations. Now, the thing is the design of the conductivity probe is very, very important. How we are going to design it because depending upon the design we can increase the flexibility or the range of identification of the flow patterns.

So, this one particular aspect I would like to discuss with you I would like to take up a horizontal pipe. Why? Because in horizontal pipe we have seen that the numbers of flow patterns are much more. What are the flow patterns can you tell me for horizontal pipe gas liquid flow, we are taking for the time being and we will be discussing same things apply for another pair of fluids as well, what are the different flow patterns that we encountered in horizontal flow louder annular slug we definitely get, definitely we would we will get annular flow pattern, slug flow pattern, bubbly let me write down first stratified.

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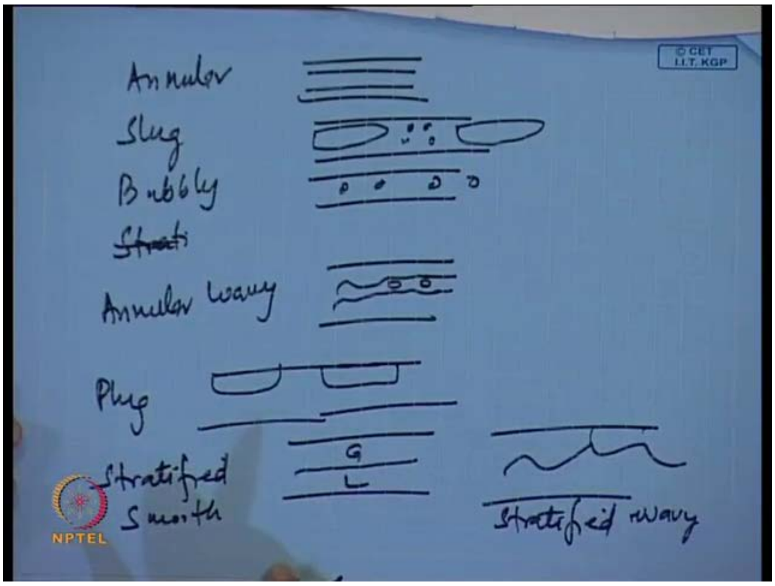

Now, stratified see annular flow pattern it will be something of this sort, we will also get one annular wavy sort of a flow pattern where more or less there will be lot of waves and definitely, the liquid film thickness will be less here and it will be more in the lower pipe and here we might get some sort of a droplet sort of a thing. We have something known as the plug flow pattern, where we have definite plugs which are flowing like this in the water and what is the slug flow pattern? In the slug definitely, we have something of this thought there are lot of aerations again, we have something of this sort.

So, this flow pattern the difference between the two is here there is no aeration here, there is aeration then we have bubbly, bubbly is very simple we have lot of bubbles of different sizes and shapes after that what we have. We have stratified flow patterns stratified there are two types this is gas this is liquid, this is a smooth stratified flow pattern and we can also have a various stratified flow pattern these waves finally, they touch the wall and they give rise to the plug flow pattern.

So, we want to identify we want to distinguish between so many flow patterns. In this particular case now, what do you expect that one particular probe at one particular location can give you so many differences. What can be the optimum design or how many probes, how they will be placed, what we can do so that from those particular signals we can actually differentiate between this one, two, three, four, five, six, seven flow, flow patterns. If we can differentiate between all of this then there is a meaning of using the opt sorry the conductivity probe for identification of flow patterns because differentiating between slug and stratified smooth that we can do visually also we do not need anything for it.

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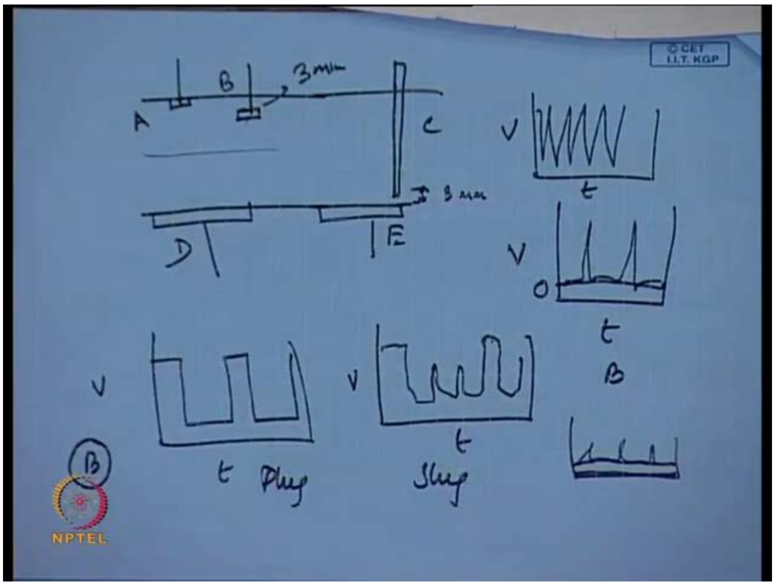

So, what will be the design of the probe for this particular purpose for design, this has been proposed by in one particular paper and I would just like to discuss it. What they did it was they used two flat plate electrodes here as one particular electrode on the probe and so, they were just mounted on the wall. What about the other electrodes one electrode was flush mounted with this wall say, this is A there was another electrodes which was say it was just inserted say about three millimeters from the wall this electrode was B and then they used in uninsulated needle, which was just three millimeters from the lower wall this was C and these two electrodes they were D and E.

So, what was measured basically the voltage across A and D was measured B and D was measured C and E were measured etcetera, etcetera. And from the outputs that we got we try to differentiate between the different flow patterns. Now, let us see how it was done say suppose, we have plug flow pattern. Plug means, what we what is going to happen we have just regular such plugs so, if we have such regular plug. What will happen? This particular B this will give you, if you take voltage verses time this will give you definitely square wave type of thing agreed and when we have slug flow pattern. What happens?

There is aeration in the liquid slugs is it not? Therefore, from this particular probe these signal definitely for this slug flow pattern, we are not going to have such nice square wave sort of a thing we will be having, having such type of a signal definitely there will be a periodic phenomena here, but there will be spikes here showing that there are aerations in the liquid slug and here also the there may be certain undulations.

So, probe B can differentiate between plug and slug by the undulations, it shows in the peaks and the valleys is it clear to you. If we take probe A what happens along probe A see one particular Taylor bubble it is, it is sliding across this. So, definitely you if you will find that definitely you will not get such nice square wave sort of a thing, but you will get some such sort of a signal so, this basically differentiates between plug and slug.

Why was this A installed here? A is installed to show whether, there is a liquid film or not if there is a very thin liquid film that cannot be detected by B that can be detected by A feel there is a liquid film, then through the liquid film the circuit is established between A and D. So, we get an output so definitely there will be different signals from A and B, if we use the or rather when it is annular flow pattern clear.

In annular flow pattern B. What you get annular flow pattern? You will, you will simply it is voltage verses time you will almost simply get some output at 0 voltage, if there are if there are certain gas say if you get something of this sort annular wavy sort of a thing then, definitely we will get some sort of spikes etcetera isn’t it. If annular flow pattern probe B you will get almost a 0 voltage output probe A since, there is a thin liquid film you will not get a 0 voltage output, you get a positive voltage output you get my point is it clear to all of you.

And if the film is wavy, then there will be oscillations of the output of A do you get the point B will always be dry. If the film is thin B will always be dry isn't it. So, it will always give you a 0 voltage output, but A when it is when it is annular smooth you will get some particular voltage here because there is a thin annular film and what will be the voltage value, it will be proportional to the liquid film thickness and if it is wavy the interfaces wavy, we will get some sort of fluctuations.

So, you can very well understand between your annular and annular wavy we can distinguish using probe A and probe B when probe B it gives you completely 0 signal for the entire time it is annular. When it give sometimes 0 sometimes positive again 0 then, it is slug. So, annular slug if you have to differentiate probe B is fine annular. Annular wavy probe A has to be used again slug and plug if you have to use then probe B was fine agreed.

Now, when you have bubbly what will you get again here more or less it is always in contact with water bubbles do not come so close to the wall therefore, you will get of maximum voltage signal from A and here very frequently bubbles will come and strike and hit therefore, for probe B what you will get voltage verses time you will get a very high voltage with large number of fluctuations. Whenever, a bubble comes and hits you will get some fluctuations get my point therefore, from here bubbly flow also you can differentiate.

So, we have differentiated between annular slug bubbly annular wavy plug everything we could differentiate. Now, what about stratified see, stratified if you just have probe A and B both of them are dry. So, how to differentiate between stratified and stratified wavy you cannot do using these two probes therefore, we have an uninsulated needle here this insulated needle it is almost three millimeters from the bottom of the pipe. So, what happens more or less if it is stratified then the naturally the liquid film thickness will be more than a liquid, if it will more than three millimeters isn't it.

So, therefore, depending upon how much of it is immersed in water, we get a signal from probe C if the signal is fluctuating, it shows we have a wavy stratified, if the signal is smooth we it shows that we do not have we have a smooth stratified film. So, remember one thing you can use a conduct and since, it is a very cheap technique you can use different designs and from these different designs, we can actually find out rather we can actually differentiate between the different flow patterns.

Now, remember one thing suppose I tell you that I differentiate between stratified wavy and smooth, then in that case you just need probe C you do not need the other probes. If we are dealing with vertical pipes and not horizontal pipes then, there are just four flow patterns bubbly slug annular churn there you do not need three particular probes. What you need? You need one wall mounted probe and this particular probe probably, it is located at the center that will give you the difference.

So, depending upon the applications you are going to decide how many number of probes and the location of probes, the design of the probes which you need in this particular case, the entire thing I have shown in the slide here. So, if you see the slide I think it is going to be little more clear. Horizontal pipe here of course, this is probe A wall mounted, probe B three millimeters and probe C here therefore, and we are measuring the voltage across probes and the wall mounted large electrodes.

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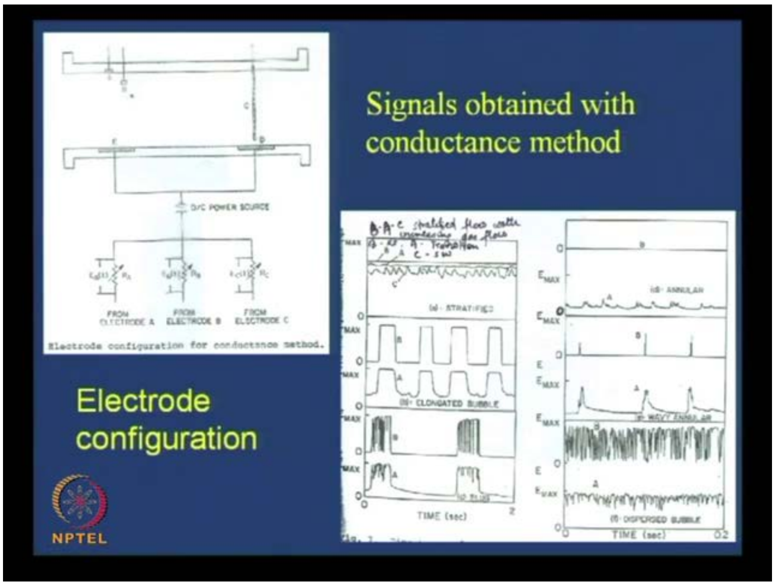

So, therefore, what do we find? If it is say elongated bubble see probe B signal, these are actual signals which we have got this probe B signals, they are square wave sort of things a signals are not so very square wave five because the Taylor bubble just slides across this therefore, since it does not hit this particular probe. So, we do not get such nice square wave sort of a thing and since there is a liquid film here; so it does not go to zero voltage you can observe we get something of this sort, which is not as good A square wave as probe B, this was plug flow or elongated bubble flow.

They say moment we get slug what happens, lot of aerations occur in the liquid slug these are the aerations, due to aerations large number of bubbles come they hit the probe. Therefore, all though the average voltage lies at a higher g max, but we have large number of aerations large Taylor bubble again, large number of aerations. so this is slug you can very well see plug and slug are very well differentiated in this C annular B it is completely dry A since there is liquid film, there is there are certain spikes here moment droplets, start coming into the liquid if sorry into the gas core we get some spikes in the 0 voltage signal of B and we get for waviness moment, waviness starts we get this sort of a signal for A.

So, you can very well differentiate between wavy annular here and annular here they are definitely different. See the dispersed bubbly sort of a situation since, large number of bubbles are coming and hitting the probe B we get such sort of a totally undulating signal, this particular signal is somewhat similar to the signal we obtain in the liquid slug for this slug flow pattern, which shows that liquid slug aerated and they resemble the dispersed vabubly distribution under that circumstances therefore, this is a dispersed flow definitely different from the plug flow or the slug flow, then we come to the stratified flow distribution, stratified you see A, B they are completely state lines.

Nothing is there they are completely state lines C, we find that there are undulations. Now, the all these signals belong to C the first signal show stratified smooth then you find slight undulations which show it is transition from stratified smooth to stratified wavy and finally what we find. We find a good amount of undulating signal which shows you it is stratified wavy. So, depending upon the design of the probe that I have that we have done, we find that we can actually identify between all the flow patterns that we can encountered in horizontal gas liquid system.

And importantly we can actually differentiate between the transition, which is very important identifying transitions is extremely important like it is very difficult to differentiate between your slug and bubbly flow. It is very, very difficult because slugs come follow very rapidly, then there is an aerated liquid slug again a Taylor bubbles always it is not very easy, but if you observe this particular probe signal you find definitely bubbly flow and slug flow are completely different in bubbly flow. We just have a totally fluctuating signal and in slug flow, if you observe this particular this slide which I have shown here, this slide, which I have shown here if you observe this particular slide here the slide which I have been shown.

So, in this particular slide we find that definitely, we have partly bubbly flow then a Taylor bubble partly bubbly flow and this is very different from plug flow these things are extremely important. So, we can actually identify moment we find from this particular plug certain undulation start occurring here we know that it is slug flow. In annular flow we find certain undulations or certain spikes start occurring in B we know it is wavy annular flow. So, this was the condition for the horizontal flow now, if we take vertical flow definitely the situation is much more simpler. Why? Because the number of flow patterns that we have to distinguish had much less in this particular case, we have bubbly flow here, we have slug, we have churn, we have annular.

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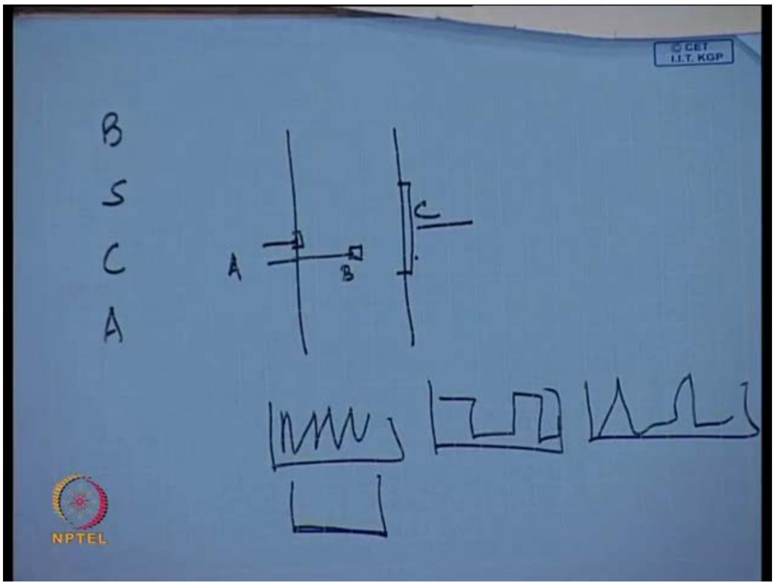

So therefore, instead of the five probe system, what we can have? We can have one wall mounted electrode here, one small electrodes, which is the probe A that I had I have said and may be one particular probe B here; we measure the effective conductivity between probe A and C, probe B and C. When it is bubbly probe B will naturally give you such sort of signals, when it is slug probe B will give you some sort of this particular signals when it is churn, it will give you some sort of this signal and when is annular, it will give you a 0 voltage signal.

So, the situation becomes much simpler in this particular case. So, this completes our discussions on multiphase flow we had first may given an introduction then, we discussed the flow patterns, we discussed the simple analytical models namely the homogenous flow theory, the drip flux model and the separated flow theory. We did part of rather we did certain we took up certain specific flow patterns; we did certain flow regimes specific models. Since, I did not have much time we just took gas liquid bubbly slug and annular flow.

And we formulated the flow regimes specific models, you had some idea regarding boiling condensation and finally, since experimentation or measurement of two phase parameters are very important in a very brief nut shell, I tried to emphasize why experimentation is difficult in multiphase flow by telling you the challenges of measuring two phase pressure drop and then, we discussed the different techniques which can be adopted for measuring the insitive void fraction and insitive composition and insitive distribution of the two phases.

Primarily, we had confined our discussions to gas liquid flow since the maximum number of work has been done on that, but the same techniques or certain modifications can be applied for other two phase flow situations as well. So, this completes our discussion on the basic of multiphase flow thank you very much.