Measurement Technique in Multiphase Flows
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Lecture – 04
Optical Fiber Probes

So, welcome back last class we were discussing about the hot wire anemometry, and we taught you briefly and in during the hot wire anemometry what I said that there is actually a wire, and you are doing the wire with the Wheatstone bridge circuit.

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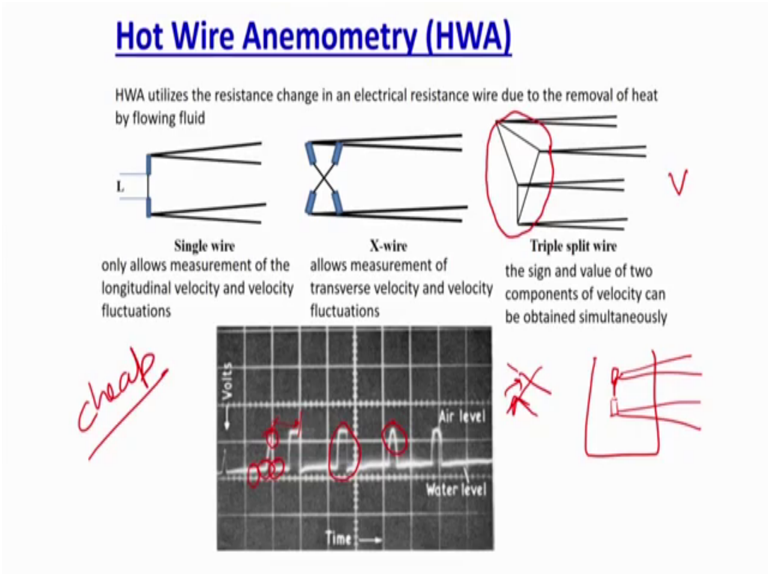

And suppose if you go it in this way just to briefly remind, what happened that there will be a wire. And once you pass a fluid the temperature will be change, and because of that the resistance of the Wheatstone bridge will also change, and you can detect the phase and based on the length we know the length of this. So, we can calculate the y velocity.

Now, the volt somehow the signal was being acquired at it in this way that, if this is the volt and this is the time. So, once you change the depending on the fluid, suppose if it is a gas liquid flow depending upon whether it is a gas flow, or it is a liquid flow, the resistance change will be different, and based on that you will get a different volt. So, this is the typical measurement, which I have already discussed and based on that you can calculate the velocity.

Now, going back again to coming back to the next section which is the optical fiber probe.

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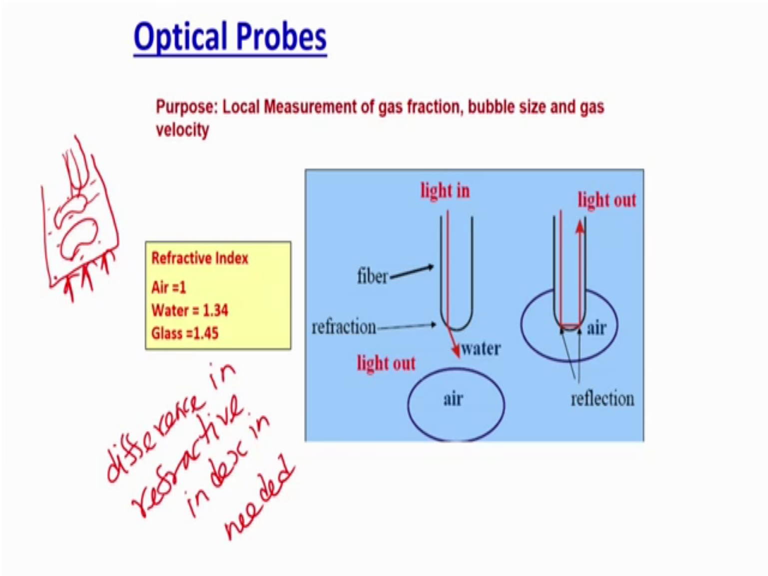

And this is a very famous technique, and we use actually very widely after the invention of the optical fibers. So, this technique actually principally works as a hot wire anemometry, but there is a difference is the way we measure the flow rates, or measure the velocity of the component. So, what is the major advantage of the optical fiber probe is that it is a very thin, it is very very small. So, the probe size is very very small it goes up to the micron level; even people are working to reduce the size of the probe further.

So, it is not bulky compared to whatever the pitot tube, and our hot wire anemometry system was there. And because they were very bulky, and very big actually they covered lot of a space inside the column, and it is that is why the change in the flow is very high compared to the optical fiber probe.

So, ideally the optical fiber probe many people believe that it is it can behaves like a non-intrusive, because the diameter of the probe is very small, but though the diameter of the probe is small it is definitely going to change something inside, yes the impact will be, but still some velocity or some volume fraction will change or will differ from the regular behavior of the column, which you will observe if you do not disturb the flow. Now what is optical probe as we know that these optical probes are based on the laser optics? So, what we do we have actually the probe available looks similar, and this probe is something looks like in this way.

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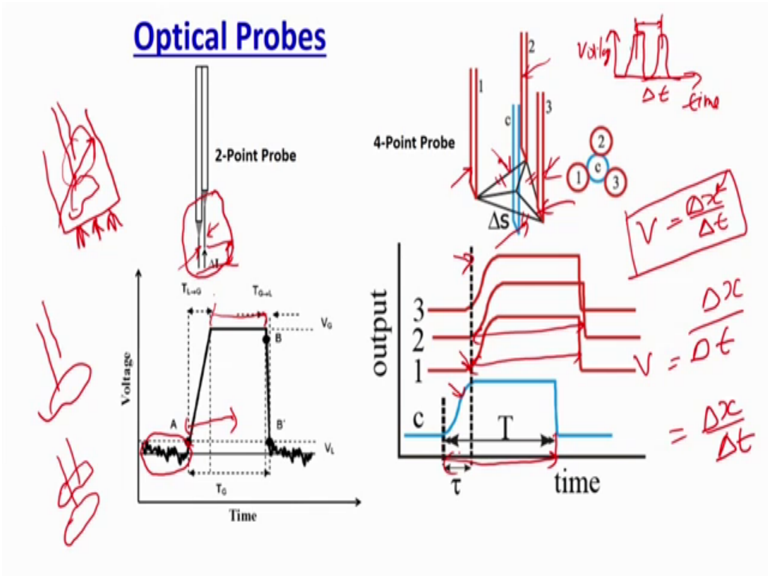

So, these are the 2 probes you can see if these are the 2 optical fiber probes. Now, it depends it works on the two principle, one is the refraction, and one is the light refraction. So, what we do one there is a, to probe there inside one is one probe actually ref emit the light, and another probe actually see the lights which is being refracted by the phase. So, if you see that this is a typical fiber in that place, one fiber will be actually emitting the light. So, you will giving a light signal in the phase of the interest. So, suppose if you have a gas liquid system again I will discuss the same suppose this is my column, and you are sparging the bubble from all gas from the bottom, it will be mean form of the bubble.

Now, if I insert optical fiber probe here. So, what will happen the optical fiber probe say this, one probe will be emitting the light. Now depending on the phase the refraction or comes from the air, refraction comes from the water will be different. So, what will happen once the bubble will come there will be a refraction in the will be there, that reflection will be a refraction actually will be different compared to the water.

Suppose if you have a solid also, then the refraction of air, refraction of water, and refraction of what this solid, all three will be different, and if the refractive index of these components are different. You will see the different signal which will be recorded by the optics probe, which will be actually nothing, but the photo detectors.

So, what will happen? So, we emit the light and based we will see the refraction. Now good thing is that most of the element, which we use generally, we know the refractive index, and if you do not know the refractive index, you can easily measure the refractive index through the refractometer which are very commonly available. So, typically say which we use in the research or in industry, we use generally air water and glass system, but for all the research purpose, we generally use this system to replicate the system which is being used in industry.

No matter whatever the system is though we are discussing for the air water in glass, but no matter whatever the system is you can easily find the refractive index the thing. Important thing is you should measure the refractive index. Now here like typically have a refractive index of 1, water has 1.34, and glasses 1.45. So, suppose if I have a system in which only air and water is there, I have 2 floors which have a different refractive index.

So, it means what they will refract the light with a different percentage, and the intensity recorded will be different. Similarly if I have a three phases the things actually hold the same way, that different phases will have a different refractive index. So, one of the major important thing which you need actually while using the optical probes is that the different phases should have a different refractive index.

So, it means the difference in refractive index is needed. So, if you want to do the optical use the optical probes with the components, which I have a very close or similar refractive index you cannot use it, but good thing is it is very difficult to find 2 fluid which having exactly same refractive index there will be difference, but difference will may be low. In case if the difference is very low, then using this kind of a technique is not possible, because light intensity will be remains almost same, and due to noise generated by the system or during the electron in because of the electronics you may not able to observe a significance difference.

So, the basic underlying principles remain same, that you are actually injecting the light, and you are measuring the refractive index, which is similar to like Wheatstone bridge, where were sorry hot wire anemometry, where you are using the change in the resistance because of the presence of the phase. Now we are measuring the change in the refractive index, because of the presence of the phase.

So, this is the way the measurement has been done. Now the good part of this technique is that you can measure the gas fraction, you can also measure the fraction of the gas, you can measure the bubble size, and you can also measure the gas velocity all 3 you can measure. And that is gives actually the boost or you can say the major advantage of this technique, that in one measurement you can have all these 3, you can measure the gas fraction, you can measure the bubble size, and you can measure the gas velocity all.

So, that is the major advantage of this technique. Now how the measurement take place I say that measurement in general take place with the measurement of the refractive index. So, what we measure again is the same, that refractive index, with the refractive index we see that how much light is being refracted. And in electronics we see it in terms of the volts. So, how much volts change you are getting based on that on the volt change will be phased on how much light has been refracted. So, how much photons actually has incident it on the photo detectors.

So, based on that you can have a voltage measurement now, the optical fiber probe is also of different type the most famous optical fiber probes are 2 point probe, and 4 point probe. So, in 2 point probe as the name suggests there are 2 probes, and you can see here there is one probe number of say one this is probe number 2, they have probe 2 probes are there. So, what happened this probe is actually dipped inside the column, in which you want to do the measurement, and this direction of the probes would be perpendicular to the direction of the, you senses the opposite, and perpendicular to the direction of the flow.

So, suppose if the flow is going from the bottom to the top, the probes would be inserted from the top to the bottom. So, this way the 2 needles of the probe should be inserted. So, what will happen suppose a bubble is coming that, bubble will actually first this probe will see that the light will be reflected by this bubble, once the bubble will touch this the refraction will be actually maximum. So, if you see here that the bubble is coming here, in this part is coming close towards the probe that is why the voltage change is being seen.

Once it comes a very close then what happens you will see the increase in the voltage, and then it remains constant for some time, because the bubble is now in touch with the probe, and then it will leave. So, you will see a change in the voltage and the change in the voltage actually suggests that bubble has actually been touched, or the phase has been changed. And that is why your overall voltage has changed from the ground level to certain under level. Now if I have a 2 probe, I will get the 2 signals, exactly in the same way, like this way if suppose I have a 2 probes says, probe 1, and probe 2, I will see that the 1s probe have a this signal, 1 probe is going with this, second probe is going with this.

So, both the probe will have approximately same thing, but I will get a 2 peaks. So, suppose this is four probe 1, if I am getting something for the probe 1 is something like this, for probe 2 again I will get something that same time. So, what I can get is that the distance between these 2 peaks, that what is the distance and that distance due to the 2 peak is actually specifying the delta t value, because the x axis is the time.

So, and this is volt. So, because the x axis is time the difference between the 2 peaks will give me the delta t, we already know that what is the delta L and delta L is nothing, but the difference between the 2 probe lengths? So, what is the distance between these 2 probe lengths, and that delta x by delta t will actually give me the velocity.

So, we can measure the velocity of the bubble, or velocity of the gas, or velocity of the phase of interest. So, we can measure that velocity with this formula. So, delta x is already know we need to find delta t and delta t can be found based on the refractive index, and which balloon index we can identify the phase, and then the time taken by that phase to travel from 1 probe to the another probe is actually the delta t. So, we can easily find it out. Now in 2 point probe the problem is actually same; which was there with the 2 point your hot wire anemometry. So, if you have a two point probe here, the problem is you will only one dimensional velocity ok.

So, in that case you will have only axial velocity, suppose you are putting it perpendicular to the flow opposite direction, then you will get only the axial velocity. Now ideally I want to measure both a radial velocity, as well as the theta direction velocity. Even if I assume that there is, no theta direction velocities; because there is primarily no motion in the theta direction.

We have already discussed that the radial velocity component can be there. So, to measure the radial velocity or to measure the other direction velocities, we have actually 4 point probe. Now why the 4 point probe is also important not only to measure all the 3 dimensional velocity, but also suppose if so, I have injected the probe it in this way, and a bubble in this way, and a bubble which is passing through this.

Now, if the bubble is passing through this line, then there is a possibility that it will not touch the second probe. And in that case you will miss the signal; you will not have the data at that point. So, there are several such combination is possible to avoid that thing we actually design a 4 port system it is being designed actually.

So, in the 4 port system as you can see in the figure, they have 4 ports this say port number 1, port number 2, port number 3, and port number 4. All the four ports are doing the same job it is injecting the light into the system, and depending on the refractive index the light received by the probe will be different, and based on the light received we can have generate voltage versus time data. And we are doing this measurement for the longer time, at a very high frequency.

So, what will happen that the first probe suppose which have a higher length, and the rest three probes in the 4 probe is being set on a equilateral triangle edges. So, suppose this is the equilateral triangle. So, this is the equilateral triangle the dimensions are equal, and the first probe is actually under centroid of the equilateral triangle. So, it goes down.

Now once the bubble comes, or once the air comes, and it touched the first bubble first or first probe first. So, what will happen you will record a signal in this way? So, we will record down the time, which is actually when the bubble has come in contact with the probe. And similarly once it will move up depending upon, whatever the direction it is moving it will see a 3 different you will see the curve of the similar type. In which if the bubble is moving vertically upward, the time recorded for each probe will should ideally be the same. So, that is what I am showing with this dotted line, assuming that the bubble is only moving upward.

So, in that case you will see the same time. So, this is the first time, and this is the time which is being recorded. What you will get? We will record the time which is bubble took or from the starting to the end. So, this is the time frame we will record for the first probe, and similarly we will record the time frames of the other probe, we will also record the time frame for the other probe.

So, what will happen the different probe is? If they are different velocity in the all the three direction the different probe will see take the different time, if the velocity is same the probes all the 3 probes will take the same time, if there is no exit velocity all the 3 probes again should see exactly at the same time. So, what will happen depending on the directions of the flow, the different probe will take different time? So, I can find it out the delta t, which has been taken from probe central probe to the different probes.

Now, if that is the case I know the delta t, I can find it out what is the velocity again by using the same delta x by delta t, and I know the distance between the bottom probe to the probes which of the interest. So, in that way what we can do? We can actually measure all the three directional velocity is needed. So, even if the bubble is passing through between this line say it is moving only in direction, which is in v r v j it somewhere in between you are actually, you can find it out the velocity. So, all the 3 component of the velocity can ideally be calculated by using of the optical fiber probes, and that is the major advantage of this.

Now, the next advantage is that you can also do the bubble size measurement. How you can do the bubble size measurement. You have a 4 probe which is being dipped inside like this, and you can see that my bubble is touching how many probes.

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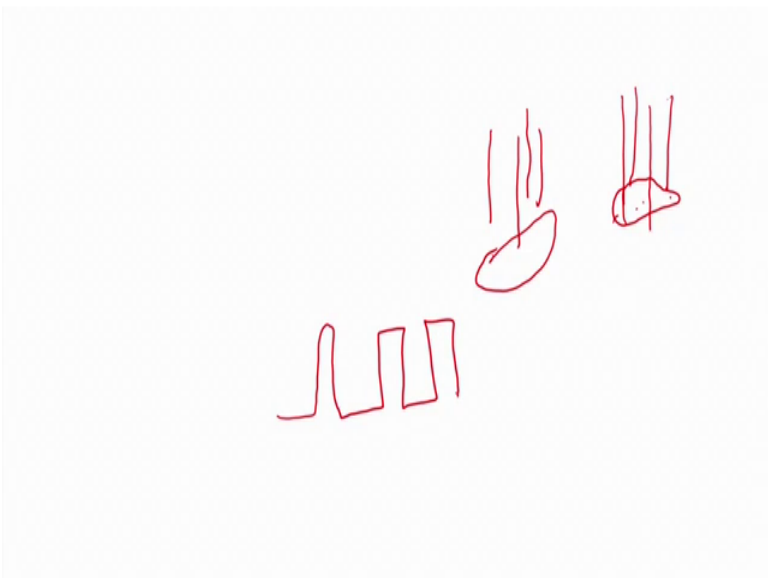

So, suppose if I have a probe, suppose this is the 4 probes. So, I can see that how many suppose there is a droplet, and this droplet is say once it will move up, it will first come in contact in this, and then once it will move up suppose this way you are seeing that how many probes what is the fraction in this your bubble is actually touching. So, based on that we can find it out what is the bubble velocity, when the signal get disturbed based on that we can also find it out that what is the roughly bubble size distribution, that you can be easily find it out.

And based on that refractive index measurement, what you first we can also calculate the volume fraction. Now how we can calculate the volume fraction, ideally whenever the bubble is touching a probe it is giving a signal like this, when again it will check the probe it we need the signal like this. So, you know that occurrences of the bubbles on the probe, and if you know the frequency of occurrences of the bubble on the probe probes, you can actually calculate the volume fraction, because the bubble occurrences will be higher at the places where the bubble volume fraction is high. So, that is the way you can also estimate the bubble volume fraction. So, that is another example and it is a very big benefit of the optical fiber probe.

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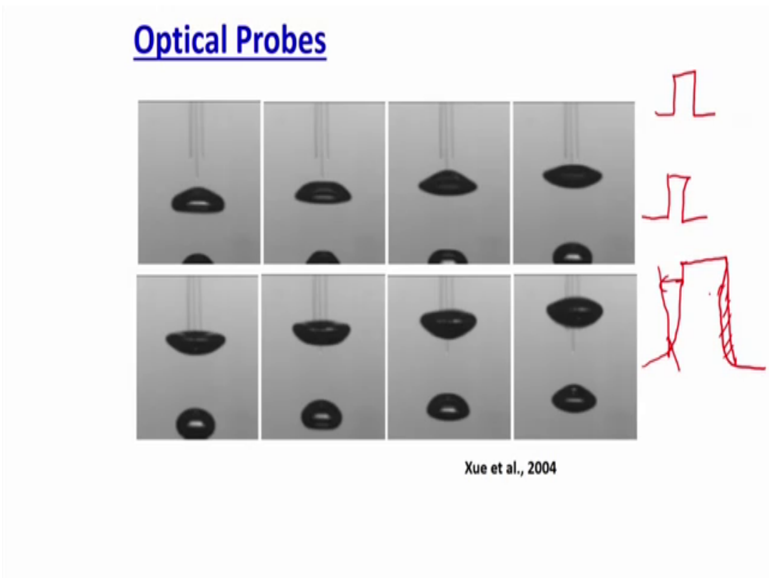

Now, how it works I just try to show a photograph which is taken by the Xue et al in 2004, and what Xue et al did actually he just injected the 4 point optical fiber probe into the fluid, and you see that once the bubble is rising actually, it is just doing the piercing job. So, this bubble is actually now inching towards the needle. And then it actually pierced through all the other probes available.

So, that is the case I was mentioning. So, what will happen after sometimes the bubble will actually pierce the probe, all the probes and then it will go outside so, it will go outside of the measurement system. So, what is the good thing here is that? The bubble piercing and you can because of that you can also measure the size of the bubble, that what will be the roughly size of the bubble, and if I measure the rate of frequency or frequency of the bubble coming to the probe, I can also measure the volume fraction at that location.

So, this is the major advantage of the technique, bubble did not burst actually because of the precise technology, and there is very small size of the needle. So, bubble actually passed through. Now that is the major advantage, but it also comes with a disadvantage. Now what is the disadvantage once the bubble passed through is that ideally speaking, I should see a on off system it means like a TTL pulse. Now what does it means ideally once the bubble is approaching towards the needle suppose this is the case, there is no bubble available at the needle right now.

So, ideally speaking your voltage should be in the range of the voltage of the pure species. So, it means what suppose this is a air and water. So, if the bubble is not touched there, this voltage will be regard will be approximately equal to the voltage which you will get once the water will be available. So, I am getting this kind of voltage suppose this is my ground level.

Now, once the air is coming in the refractive index value will change, and say I am increasing the voltage. So, voltage will actually increase. Then till the bubble is not piercing the voltage will remain same, and then it will leave the column. So, you will see a TTL kind of a pulse which will be quite stable and easy to use, but in reality what happened that because the bubble is coming here, it is not just touching the column at 1 go, it is actually staying some time with the probe.

Now because it is staying some time with the probe, what will happen initially the value will be 0, then it will slowly start increasing once it will start increasing, because now the bubble comes very close, and now it is piercing so, during the time of piercing the bubble this voltage will remain same. And then it will slowly decrease, then it should come to the 0.

Now, this part which I said that it is slowly increasing it is not a TTL. So, this part is actually dicey. Similarly this part is actually dicey yet how to calculate this part. Experimentally it is easy to calculate because I can find it out the delta t, but the problem is because of the noise, now if you see this data because of some noise, the starting point is also difficult to measure. Second thing it is very difficult to measure the delta t, because this slope can be different for the different probes. Now if suppose you are using four probes, the slope will be different from the probe 1 and probe 2; so, they will be different. Similarly probe 3, and probe 4 this this also will be different.

So, what will happen that because there is they are different, what will happen use very difficult to find it out the exact delta t now the overall problem is that you are measuring the velocity with the delta x by delta t. Now a small error in the delta t, because delta x is also very small, the difference between these 2 probes is very very smaller probe is very very small, what will happen the small error in the delta t will cause a huge error in the velocity measurement, and that is the major problem. Now this piercing create that problem actually.

Now, what is another problem is that because of this actually, because of this piercing, you is, are not able to measure the exact delta t. You will have to approximate that from where I start that time. So, few people say that you should start this delta t, you should take some people say that you should take the half of this, this delta t it means delta t from this. And some people agree that I should take the delta t which is actually I should start from this place, and see that whenever it is coming out. So, I should take that much delta t.

So, that is the reason that and I already said that a small error in the delta t, will actually cause a big error in the velocity measurement. And the major reason is the delta x by delta t which you are using. So, calculating the delta t itself is a big issue here, and even with the different probes the issue becomes even more complicated, depending upon the piercing of each probe. Now this piercing can change depending upon the direction of the flow. So, that is why it is very difficult to standardize that this much time will be because of the piercing, or this much time the voltage rise has been taken, and that rise actually is mainly because the interface issues.

Now, to resolve that or it is very actually difficult to resolve. So, what can be the other first thing? So, the other option though to resolve this problem, or you want to resolve this or minimize this problem. What we can make? We can make a probe which is really hydrophobic in nature. So, what I we do that I will put some coating, some paint, which will actually reduce the cyber on this is to make it hydrophobic. And in that case the piercing issues, or the change in the voltage issues, which is being actually being minimized or being increasing very slowly, and you have by small TLG lag is there that actually you can minimize.

Now, it is very difficult actually to make the surface which is 100 percent hydrophobic, and that is why this error is still there. Now there can be another problem because of this. So, what is that problem? That suppose if the bubble velocity is too high, a bubble generation frequency is too high, then what will happen that suppose these are my 2 probes.

So, same time many bubbles will be actually touching this probe, many bubbles the touching this probe means, suppose this is my 1 bubble which test the bottom probe first, and that by the time it is reaching to the top floor top probe, in this the another bubble is touching to the bottom probe. So, in such situation taking the delta t or is becomes very even more complicated, and it may cause an error in the velocity measurement, that is why it is reported that sometimes it is not being used properly. The optical fiber probe can generate error of around 150 to 200 percent, but really for a very high velocity system, where the bubble generation rate will be also very high.

So, that is actually a major drawback of this optical fiber probe, method that if you have a bubble generation rate, bubble formation rate it is very high, you velocity is very high. Then the use of optical fiber probe is actually limited. Another disadvantage or bigger disadvantage is that, which was the advantage earlier I said that the probe size is very small. Now if the probe size is very small if you use in case of the solid, the chances that the probe will get damaged is very very high. So, it means what you can damage your probe, and this is, are the costly probe, these are the costly probes. So, if you damage your probes very frequently the cost of the measurement will goes really very high.

Otherwise it is considered a very easy way to implement; the implementation part is very easy. The measurement part is easy the only thing is to measure the delta t accurately. So, that is about the optical fiber probes, people has implemented optical fiber probe in gas liquid system, in the liquids liquid system, in the gas solid system, or as is realized in the liquid solid system.

Though the major application you will find is for the gas solid gas liquid system, and you can also because you can also measure the bubble diameter. So, this was all about the optical fiber probe, and with this I can conclude the non-invasive technique part. So, we have calculated in the noninvasive velocity measurement, we have seen the technique, which is a pitot tube, we have discussed about the hot wire anemometry, we have discussed about the optical fiber probe. We have discussed the working principle measurement, principle and how to calculate the velocity in all this the velocity can be calculated by the delta x by delta t, while in pitot tube the velocity can be calculated by measuring the pressure drop.

So, this is all about the optical this noninvasive technique sorry. So, this is all about the invasive techniques. Now we as we keep on discussing that, because these techniques are invasive you are putting something inside, you are actually changing the measurement field off flow measurement itself, because the flow field itself is being changed. So, to overcome this we can have a, non-invasive techniques.